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A
T R E A T I S E
O N
M A G N E T I S M,
I N
T H E O R Y A N D P R A C T I C E,
W I T H
O R I G I N A L E X P E R I M E N T S.
B Y
T I B E R I U S C A V A L L O, F. R. S.

L O N D O N:
P R I N T E D F O R T H E A U T H O R ;
A n d s o l d b y C. D I L L Y, i n t h e P o u l t r y; P. E L M S L Y,
i n t h e S t r a n d; a n d J. S T O C K D A L E, i n P i c c a d i l l y.



T H E P R E F A C E.

THE importance of the subject of magnetism, principally in navigation, and the obscurity of the cause which produces its wonderful phenomena, has, from ages, excited the attention of very able philosophers and mathematicians, who, with diligent assiduity, and profound consideration, have examined the properties of the magnet, and have framed hypotheses

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theses for their explanation. Several of those labours, though not crowned with discoveries, are nevertheless exceedingly ingenious, and deserve some attention.

To arrange those observations in a proper order, to describe the various hypotheses, and the manner in which the phenomena of magnetism have been attempted to be mathematically deducible from them, was the author's original intention ; but when the work was nearly accomplished, its great bulk, and the intricacy of the mathematical part, incompatible with the genius of the generality of readers, and even with the patience of mathematicians ; considering that those calculations were seldom productive of remarkable consequences ; the original

original plan of the work was relinquished, and much labour was bestowed in divesting it of the abstruse part, and contracting it into the form in which it is now made public.

The object then of the following Treatise is to exhibit a comprehensive view of the present state of knowledge relative to magnetism; the author having disposed the various particulars in that order which seemed most likely to lead the reader from the simplest to the most intricate and depending part of the subject, by the plainest and shortest ways.

The first Part treats of the laws of magnetism, *viz.* of those properties, and their limits, which have been ascertained by a great number

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ber of experiments and observations, and which are independent on any hypothesis.

In order to distinguish the knowledge of certain facts from the supposition of their causes, and the improbability of most of those suppositions, the second, and by far the shortest, Part of the book, has been allotted to the hypotheses of magnetism.

The third Part treats of the practice of the subject, *viz.* it contains a series of such experiments as are necessary, and sufficient to demonstrate the certainty of the laws mentioned in the first Part, and to employ them for the various purposes to which they are subservient.

The fourth, and last Part, contains

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tains the various experiments made by the author himself, relating to magnetism.

There will be also found interspersed throughout the work, various remarks and hints, useful to those who may be willing to promote the farther investigation of the subject; but, on the other hand, the author has thought proper to omit several trifling particulars, which might be easily suggested by the ingenuity of the reader, and divers experiments, which seemed to be only variations of those inserted in the book.

Lastly. To render the work more perspicuous and useful, two copper-plates and a copious index have been added to it.

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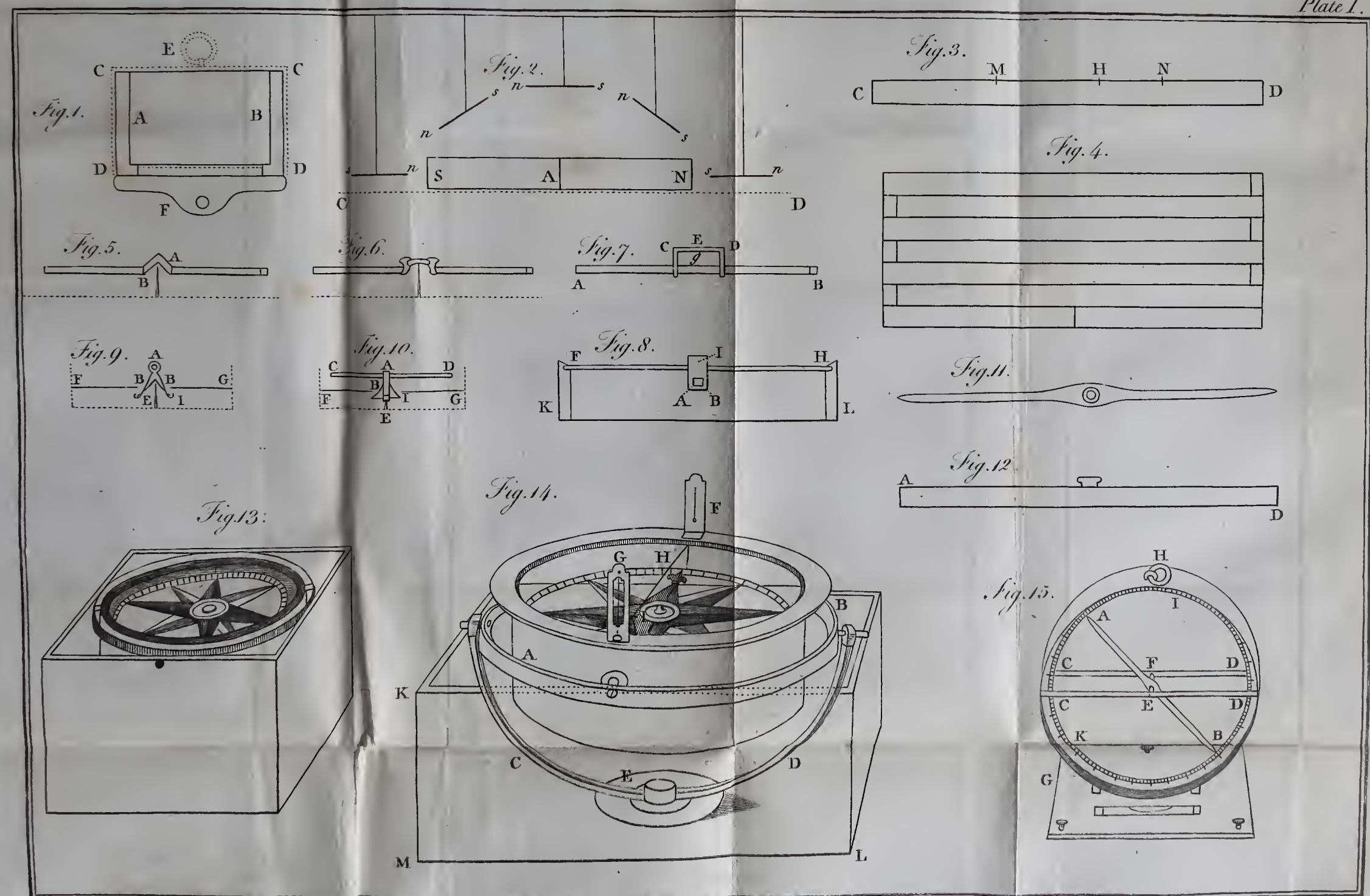
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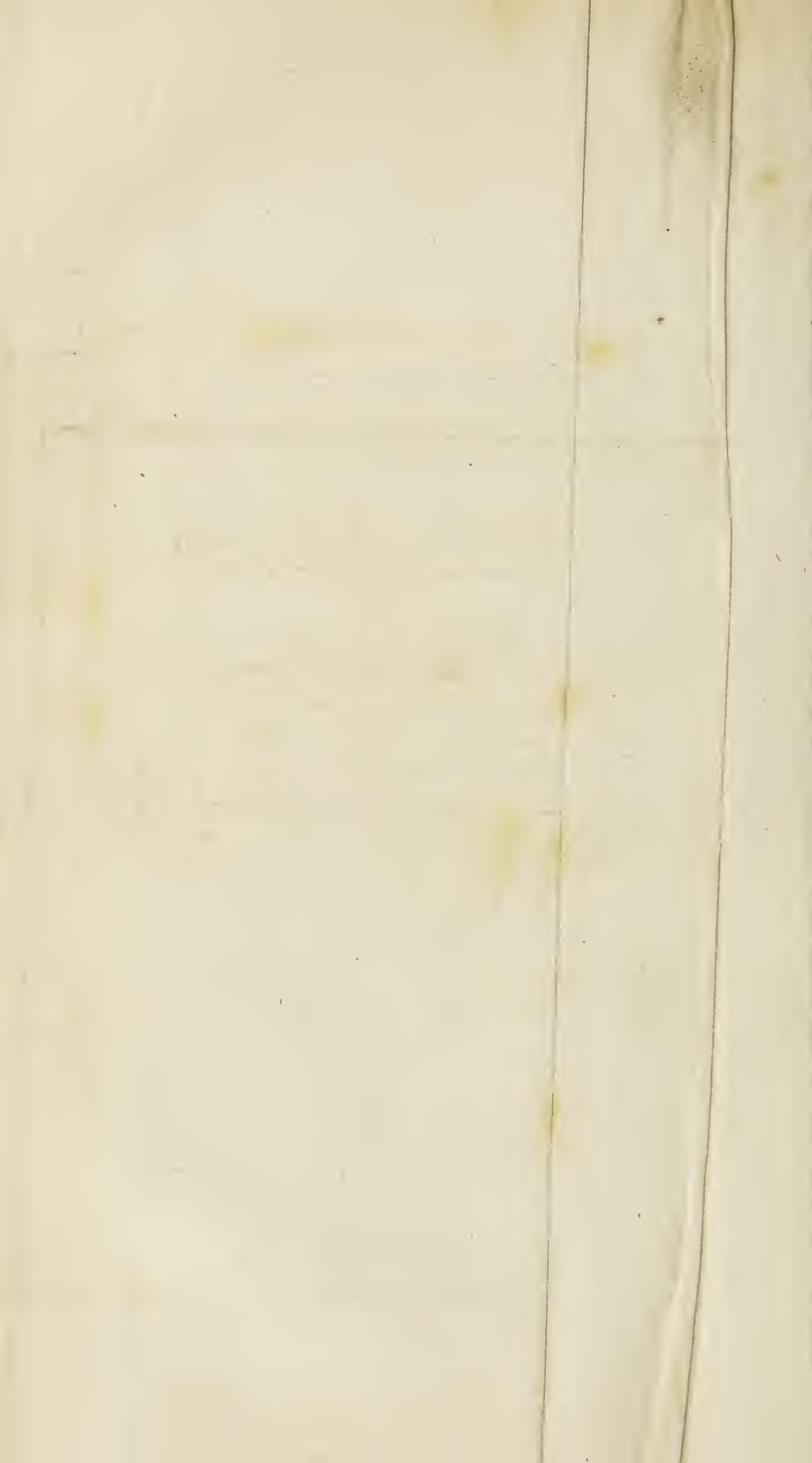
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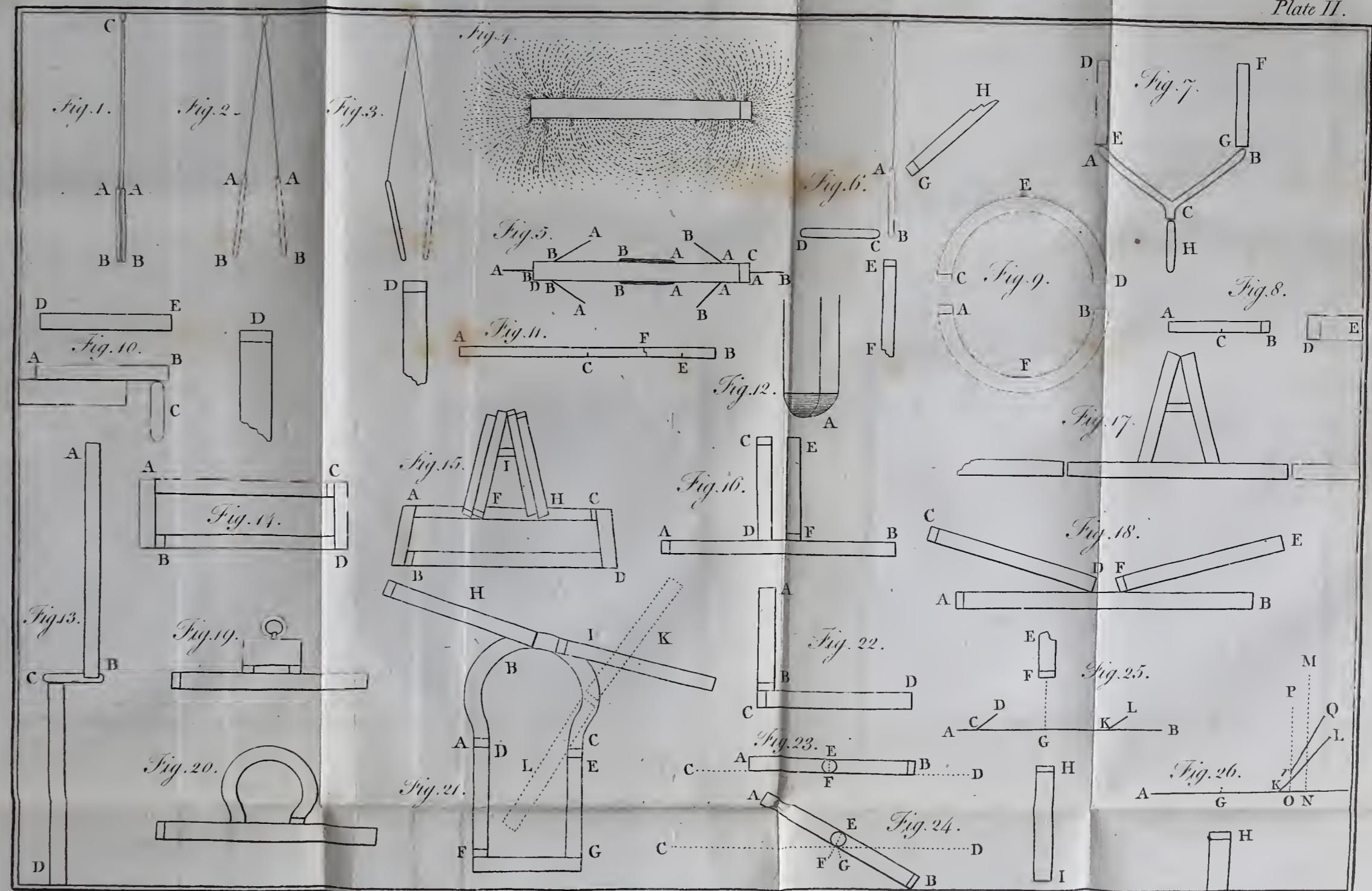
Page 4, line 7, for north read south.
Page 68, line 17, for attracted read are attracted.
Page 166, line 24, for E F read I K.
Page 175, line 9, for round the read round to the.
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Plate I.







P A R T I.

L A W S O F M A G N E T I S M.

C H A P T E R I.

*Containing a general idea of Magnetism, and
the explanation of the technical words.*

A SOLID mineral body, which has the property of attracting iron, or ferruginous substances, besides other properties peculiar to itself, has been called a *natural magnet*, or *load-stone**. And, as

the

* The word *magnet*, by some ancient writers, is derived from the name of a shepherd, by whom they suppose the magnet to have been first discovered on mount Ida. It has been more commonly called *lapis Heracleus*, by Pythagoras, Aristotle, Euripides, and

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the same properties may be communicated to iron, steel, and other ferruginous substances; those bodies, after having acquired the magnetical properties, are called *artificial magnets*.

A magnet, whether natural or artificial, is always possessed of the following characteristic properties, which are inseparable from its nature; so that a body cannot be called a magnet unless it be possessed of all those properties at the same time: neither is there any instance of a magnet's being produced, which had only one or a few of those properties, without shewing any of the rest.

1. A magnet attracts iron and other ferruginous substances.

2. When a magnet is placed so as to be at liberty to move itself easily, as, if it be suspended by a thread, &c. it turns one, and constantly the same part of its

others, from Heraclea, a city of Magnesia, a part of ancient Lydia, where it is supposed to have been first found. It has likewise been called *lapis nauticus*, from its use in navigation; and *siderites*, from its property of attracting iron, which metal is called σίδηρος in Greek.

surface

surface towards the north pole of the earth, or towards a point not much distant from it; and of course it turns the opposite part of its surface towards the south pole of the earth, or towards a point not much distant from it. These parts on the surface of a magnet are therefore called its *poles*, the former being denominated its *North pole*, and the latter its *South pole*. The property itself is called *the magnet's directive power*, or *magnetic polarity*; and when a magnetic body places itself in that direction, it is said to *traverse*. A plane perpendicular to the horizon, and passing through the poles of a magnet when standing in their natural direction, is called the *magnetic meridian*: and the angle made by the magnetic meridian and the plane of the meridian of the place where the magnet stands, is called *the declination of the magnet*, or more commonly *the declination of the magnetic needle*; because the artificial magnets, mostly used for observing this property, are generally made slender, and somewhat in the shape of a needle; or because real sewing needles

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themselves have been often used for this purpose.

3. When two magnets are placed so that the north pole of one is opposite to the south pole of the other, then they attract each other ; but if the south pole of one magnet be placed opposite the ~~north~~^{south} pole of the other magnet, then they repel each other. In short, magnetic poles of the same name repel one another, whereas those of a different name attract each other.

4. When a magnet is placed so as to be at liberty to move itself very easily, it generally inclines one of its poles towards the horizon, and of course it elevates the other pole above it. This property is called the *inclination* or *dipping* of the magnet, or more commonly, *of the magnetic needle*, for the reason above-mentioned.

5. Lastly ; Any magnet may, by proper methods, be made to impart those properties to iron, steel, or, in short, to most ferruginous substances.

The experience and industry of mankind have gradually discovered, examined, ascertained, and employed for various useful

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ful purposes, those magnetical properties ; and it is the object of this work to describe, in a concise and perspicuous manner, the laws, which have been ascertained by those innumerable observations, and the uses to which they have been rendered subservient. Those laws and their uses are methodically laid down in the following pages, there being allotted to each chapter those particulars, which were most connected with each other : but, as the whole action of magnetism seems to be confined solely or principally to iron, and to those bodies which contain that metal in some state or other, it will be necessary to premise the natural history and chymical properties of that substance, at least such as may be deemed necessary for the comprehension of the subject, or likely to open the way to farther discoveries.

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C H A P T E R II.

The natural history and principal properties of Iron ; and of the natural Magnet, or Loadstone.

IRON is, of all the metals, the most subservient to human life ; and, at the same time, it is very remarkable, that its nature is far from being perfectly understood, or sufficiently investigated. It is reckoned amongst the imperfect metals, on account of its being subject to rust or calcination ; and its specific gravity, though subject to a little variety, yet is seldom, if ever, less than 7,6, or exceeds 8 times the weight of distilled water.

Iron is found almost in any place, and is extracted from the bowels of the earth, it being therein found either by itself in a metallic state, which is called *native iron*, or mixed with various other substances ; which compounds, when the iron or martial part contained in them is in a considerable proportion, are called iron ores.

The

The iron ores described by the latest mineralogists, and their principal names, are the following:

1. *The steel ore*, which consists of a brown calx of iron mixed with iron in its metallic state.
2. *The magnet*.
3. A mixture of the brown calx of iron and plumbago.
4. *The white or sparry iron ore*; being the brown calx of iron united to the white calx of manganese.
5. *The magnetic sand*.
6. *Hæmatites*; consisting of the red calx of iron indurated, and combined with a little argill, and frequently with manganese.
7. *Hæmatitical yellow, red, and brown ochres*; consisting of hæmatites in a loose form, mixed with a considerable proportion of argill.
8. A combination of the red calx of iron with plumbago.
9. *Torsten*; being a mixture of the red calx mixed with a small proportion of the brown and indurated calx of iron.

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10. *Emery.*
11. *The grey iron ore*; consisting of the red calx united to siderite.
12. The argillaceous iron ores; the two species of which are, the highland argillaceous ore, *minera ferri ochreacea*; and the swampy argillaceous ore, *minera ferri lacustris vel subaquosa*.
13. *The red calcareous iron ore.*
14. *The siliceous iron ore.*
15. *The muriatic iron ore.*
16. *The martial calamine.*
17. *Martial pyrites*, which consist of iron mineralized by sulphur.
18. *The white, grey, or blueish-grey pyrites. Marcassite*; being iron mineralized by sulphur and arsenic.
19. *Mispickel*; consisting of iron mineralized by arsenic alone.
20. *Combustible iron ore.*
21. *Green vitriol*, being iron mineralized by vitriolic acid.
22. Iron mineralized by the phosphoric acid; the two species of which are, *the siderite*, and *the native Prussian blue*; the latter

ter of which consists of iron, phosphoric acid, and argillaceous earth *.

In extracting the metal from the various iron ores, two objects must be considered, *viz.* the state of the iron, which is in a more or less metallic state, and the extraneous substances which are mixed with it. On those accounts, it is almost impossible to prescribe the most advantageous method of extracting the iron from a certain ore, without making particular experiments upon it. However, the principal agents in this operation are, a strong heat, and the admixture of substances capable of furnishing the inflammable principle.

The iron, after being extracted from the ore, and being reduced into the metallic form, is not always of the same nature; and its various species, the principal of which we shall now enumerate, are possessed of peculiar and very remarkable properties.

Cast iron, *viz.* iron after having been fused by the action of a strong heat, is very

* See Bergman's mineralogy, Kirwan's mineralogy, and my mineralogical tables.

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hard and brittle, so that it cannot be formed into any required shape by hammering, nor even by filing.

The malleable iron is formed from the cast iron, by exposing it to a strong blast of air for some hours, whilst it stands in a red or rather white heat. It is remarkable, that in this process a quantity of liquid matter comes out of the iron, which when cold is in the form of black cinders, called *finery cinders*, from the name of the furnace employed for the process *.

The malleable iron is of two sorts, *viz.* that called *red short iron*, which has the property of being malleable when cold, but brittle when hot; and that called *cold short iron*, which is malleable when red hot, but brittle when cold.

Steel is formed from iron, by exposing the iron to a strong heat for several hours, whilst it is surrounded by substances that contain a great deal of the inflammable principle, as charcoal, oleaginous substances, &c.: hence it is generally believed,

* See Priestley's experiments relating to various branches of nat. phil. vol. iii, sect. xxiv.
that

that the iron becomes steel only in consequence of its acquiring a greater quantity of the inflammable principle, called *phlogiston* by the chymists ; but there is some sort of malleable iron which will never become steel ; and I am informed by a very ingenious chymist, that this effect is owing to the want of the semi-metal called manganese ; this gentleman having found, that the iron, which is wont to be capable of becoming steel, contains some portion of manganese ; whereas, that sort of iron which is incapable of becoming steel is quite free from any admixture of that semi-metal.

By the transition from iron into steel, the weight of the metal is not at all, or very little, increased ; but it acquires several remarkable properties. Steel is generally harder than malleable iron ; it may be hammered when cold, but incomparably better when red hot ; it may be fused ; and it is capable of acquiring various degrees of hardness. Hammering will harden it to a certain degree ; but if it be made red hot, and in that state be plunged into cold water,

water, or other cold liquor, so as to cool it suddenly, it becomes exceedingly hard and brittle, so that it can neither be hammered nor filed ; and, the greater the difference between its degree of heat and that of the liquor, in which it is plunged, the greater is the degree of hardness it acquires. The steel, after having been thus hardened, may be softened to any required degree, by exposing it to a proper heat, which operation is called *tempering*. The softening by this means is accompanied by a gradual change of colour ; which colour, however, is merely superficial, but remains as long as the steel is not rubbed with something capable of scraping off part of the metal. Thus, if the hardened piece of steel be laid upon a red-hot iron, or be heated in any other manner, it will first acquire a reddish, then a yellowish or straw colour, which will gradually deepen, and change into blueish, deep blue, and lastly, the steel becomes red hot. Now, if the piece of steel be removed from the heat just when it has acquired the straw-colour, it is then softened a little, and just sufficiently

sufficiently to serve for points of drills, and some other tools; hence this degree of softening is called *drill temper*. If the piece of steel be removed from the heat as soon as it becomes blue, it will be found to be softened sufficiently to serve for springs; hence that degree of softening is called *spring temper*. If the steel be suffered to become red hot before it be removed, it will be found to have lost all the hardness which it had acquired in the first process.

By repeated hardening and softening, a piece of steel becomes less and less fit for nice work: but even in steel newly formed, there occurs a considerable variety; and that sort is reckoned the best, which in its fractures exhibits a small, uniform, and silvery granulated appearance.

All the above-mentioned species or states of iron are capable of calcination, *viz.* of being reduced to rust, and of course, to various intermediate states between that of good metal, and that of red calx. This change, according to the

more

more general opinion, is occasioned by the escape of the inflammable principle; and in fact, if the calx of iron be exposed to a strong heat whilst it is surrounded by charcoal-dust, or other substance abounding with phlogiston, the calx will become iron again.

In the following pages, for the sake of brevity, we shall comprehend all the above-mentioned states or species of iron under the general appellation of *ferruginous substances*; adding the word *metallic* to those which are in a metallic state, and the word *calcined* to those which are in a calcined state.

A remarkable phænomenon happens in the calcination of this as well as of other metals, which is, that the metal acquires weight by being calcined, and the calx loses weight by being reduced again into metal. Thus it has been observed, that 100 grains of the brown calx of iron will produce about 85 grains of iron; and 100 grains of the red calx will produce about 75 grains of iron: and, on the contrary, the above-mentioned quantities of iron will produce

produce 100 grains of the brown or red calx respectively.

This increase of weight has been ascertained to be owing to a certain permanently elastic fluid or sort of air, which combines with the calx in a greater or smaller proportion, according as the calcination is more or less perfect ; and the diminution of weight observed in the reduction of the calx into metal, to be owing to the escape of that same elastic fluid from the calx. Upon these grounds, some ingenious persons have imagined, that the calcination of a metal, or the reduction of the calx into metal again, had nothing to do with the inflammable principle or phlogiston of the chymists ; but that it was all to be explained by the loss or acquisition of the said permanently-elastic fluid.—Various arguments and experiments seem to favour each opinion ; but the nature and limits of the present work not permitting me to expatiate on this subject, I must refer those readers, who are desirous of examining it farther, to other books, where they may be informed not only of the above-mentioned subject,

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subject, but likewise of the particulars concerning the elastic fluids which may be obtained from the solution of iron, and of other properties relating to this most useful metal *.

The metallic ferruginous substances are soluble in all acids, though not with equal facility ; and if any vegetable astringent be added, the solution will become black ; but if phlogisticated alkali be added, instead of the vegetable astringent, then the solution will become blue.

The natural magnet, mentioned at the beginning of this chapter, is an ore of iron ; and it contains a greater quantity of iron, either in the metallic state or not much dephlogisticated, than most other iron ores. However, though every magnet seems to contain some iron in a metallic state, yet it does not follow that every ore, which contains the iron in that state, is magnetic ; there having been found many iron ores,

* Hist. de l'Acad, since the year 1778.—Priestley's Experiments and Observations relating to the different sorts of Air, &c.—Rozier's Journal de Phys. for September 1786—and my Treatise on Air and Permanently Elastic Fluids.

which

which had all the appearance of good magnets, but were not possessed of the magnetic properties *.

Besides the iron particles, the natural magnets often contain a portion of quartz and argill, and probably some sulphur, because when made red hot they generally have a sulphureous smell; besides which, many other substances may be found in them, though not so frequently as those mentioned above.

Magnets differ in specific gravity according to the proportion and nature of the other ingredients that are mixed with the iron or martial part, but generally they are about seven times heavier than distilled water.

Their colour is mostly a dull brownish black; though, as may be imagined,

* Some old writers on magnetism make mention of certain load-stones so light as even to swim upon water. But as iron is so universally spread throughout the works of nature, it is not improbable that some light, spungy, volcanic productions may contain a quantity of iron particles with some vestiges of magnetism, sufficient to give the name of magnet to the whole mass.

a considerable difference is often occasioned by the admixture of heterogeneous substances, and by the state of the iron contained in them. The magnets which are found in Arabia are reddish, those of Macedonia are blackish, and those found in Hungary, Germany, Britain, and Italy, have mostly the colour of unwrought iron.

The hardness of magnets is such as just to afford sparks when struck with steel; but it is extremely difficult to turn them in a lathe or to shape them by a file.

It has been observed, that generally those magnets, which have a fine close grain, are more powerfully magnetic, and retain the virtue much longer, than those which are of a coarser grain; and even longer than the artificial magnets which are made of steel.

They are found in many parts of the world, and almost wherever there is a good iron mine. In Europe they are met with pretty frequently, in the mines of Germany, in the Apennines, in France, in the islands of the Mediterranean Sea, in Britain, in Ireland,

land, and in various other places. Asia does likewise abound with magnets; neither are the other parts of the world without them, though not very copiously; or perhaps for want of sufficient examination so great a quantity of magnets has not been found in them as in Europe and Asia.—They are not found of any particular shape or size.

CHAPTER III.

Of Magnetic attraction and repulsion.

THE various sorts of attraction hitherto discovered may be reduced to five: *viz.* 1st. The attraction of gravitation, or that power, by which bodies fall towards the centre of the earth, and by which the immense bodies of our planetary system are retained within their proper orbits. 2. The attraction of cohesion, which takes place when the parts of bodies are put in close contact, as when two smooth, and like surfaces of metal,

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glass, marble, or other substance, are pressed one upon the other. 3. The chymical attraction, or affinity, which occasions an intimate mixture, and alteration of two or more substances of different natures. It requires the immediate contact of the parts of the bodies, in order to take place. Such is the attraction between acids and alkalies, between acids and metals, &c. 4. The attraction of electricity, possessed by all sorts of bodies when electrified ; which acts on substances of every kind, and extends its sphere of action to a considerable distance. 5. Lastly ; The attraction of magnetism, which acts only upon iron, or upon those bodies which contain that metal in some state or other ; hence, besides other obvious peculiarities, this sort of attraction may be easily distinguished from the rest.

A piece of iron, or steel, or other ferruginous substance, being brought within a certain distance of one of the poles of a magnet, is attracted by it, so as to adhere to the magnet, and not suffer to be separated without an evident effort. This attraction

traction is mutual; so that the iron attracts the magnet as much as the magnet attracts the iron; for if they be placed on pieces of wood, so as to float upon the surface of water, it will be found that the iron advances towards the magnet, as well as the magnet advances towards the iron; or if the iron be kept steady, the magnet will move towards it.

The strength or degree of magnetic attraction varies according to different circumstances; namely, the strength of the magnet, the weight and shape of the body presented to it, the magnetic or unmagnetic state of that body, the distance between it and the magnet, &c.: which particulars we shall now examine in their order.

A magnet attracts a piece of soft and clean iron more forcibly than any other ferruginous body of the like shape and weight. The iron ores, amongst which the natural magnet is comprehended, are attracted more or less forcibly, in proportion as they contain a greater or less quantity of metallic particles, as that

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quantity is in a more or less perfect metallic state, and as it is of a softer or harder nature; but they are all, as well as hard iron and steel, attracted less forcibly than soft iron.

If a piece of iron be presented successively to the various parts of the surface of a magnet, it will be found that the attraction is strongest at the poles of the magnet (*viz.* those parts of the surface which, when the magnet is freely suspended, are directed towards the north and the south); that the attraction diminishes in proportion as the part of the surface to which the iron is presented recedes from the poles; and is very little or not at all perceptible about those parts of the surface, which are equidistant from the poles.

The attraction is strongest near the surface of the magnet, and diminishes as it recedes from it: *viz.* if a piece of iron be placed in contact with one of the poles of a magnet sufficiently strong, they will adhere to each other, and there is required a certain force to separate them; but if the

same

same piece of iron be kept at an inch distance from the same pole of the magnet, there will also be perceived an endeavour to attract it; but the force required to prevent the iron running to the magnet will be found to be much smaller, than that which was required to separate them in the first case; and if the iron be held at a distance greater than one inch, the attraction will be found to be still weaker; and so on.

Though the attraction between the magnet and the iron, or other ferruginous body, is stronger within a short distance than farther off, yet the law of that diminution has not yet been ascertained, notwithstanding the repeated endeavours of the greatest geniuses philosophical and mathematical. For instance, it is not known whether, at a given distance, the attraction of a magnet in general is twice, three times, or any other number of times greater than at double that distance. The analogy of other energies, which being propagated from a centre, and expanding into a sphere, have their

densities diminished in the proportion of the squares of the distances would easily persuade one to expect the same law in magnetics; but experience does not shew it. Various accurate experiments, made by different philosophers, have been attended with different results. In some, the attraction seemed to decrease in the inverse ratio of the distances, with sufficient regularity; but in others it decreased much faster, or in different proportions at different distances: so that the only general conclusion, which may be inferred from them, is, that the decrease of magnetic attraction is not slower than the inverse ratio of the distances; *viz.* at double the distance the attraction is half as strong, or rather less; at treble the distance the attraction is one third as strong, or rather less; and so on *.

In order to give the reader an idea of the above-mentioned irregularity respecting

* From some other experiments made with magnetic needles, which will be considered in the sequel, it appears that the attraction decreases in the ratio of the cubes of the distances.

magnetic attraction, and also of the distance to which it may extend itself, I shall subjoin four experiments, accurately made by the learned Musschenbroek *.

EXP. I. A cylindrical magnet, two inches long, and weighing 16 drams, was suspended to one scale of an accurate balance, and under it there was placed, upon a table, a cylinder of iron, which was exactly of the same bulk and shape. Things being thus prepared, the cylinder of iron was successively placed at different distances from the magnet, and at each distance the degree of attraction between the iron and the magnet was ascertained by weights put in the opposite scale of the balance. The results were as follow, *viz.*

Distance in inches.	Attractions in grains,
6	3
5	$3\frac{1}{2}$
4	$4\frac{1}{2}$
3	6
2	9
1	18
0	57

* Introduction to Natural Philosophy, chap. xix.

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EXP. II. A spherical magnet, of the same diameter as the cylindrical one used before, but of greater strength, was affixed to one of the scales of the balance ; and the cylindrical magnet, used in the preceding experiment, was placed upon the table, with its south pole upwards, and facing the north pole of the spherical magnet. In this disposition of the apparatus the attractions were found to be as follows :

Distance in inches.	Attractions in grains.
6	—
5	—
4	—
3	—
2	—
1	—
0	—

EXP. III. Instead of the cylindrical magnet, the cylinder of iron was placed upon the table, and under the globular magnet. The result was as follows :

Distance

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Distance in inches.	Attractions in grains.
6	—
5	—
4	—
3	—
2	—
1	—
0	—
	7
	9 $\frac{1}{2}$
	15
	25
	45
	92
	340 *

Exp. IV. Instead of the iron cylinder, a globe of iron of the same diameter as the spherical magnet was placed upon the table, and the attractions were found to be as follows :

Distance in inches.	Attractions in grains.
8	—
7	—
6	—
5	—
4	—
3	—
2	—
1	—
0	—
	1
	2
	3 $\frac{1}{4}$
	6
	9
	16
	30
	64
	290

* The same magnet was found to attract a shorter cylinder of iron with less force, but in the same ratio,

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From the second and third experiments it appears, that, when in contact, a magnet attracts another magnet with less force than a piece of iron. This has been confirmed by many other experiments. But the attraction between two magnets begins from a greater distance than between the magnet and iron; hence it must follow a different law of decrement.

The attraction between a given magnet and a piece of iron is subject to a variation arising from the weight and shape of the iron; there being a limit, in the weight and shape of the iron, in which the magnet will attract it more forcibly than either a greater or a smaller one: but this most advantageous weight and extension of the piece of iron can only be determined by actual experiment, it being various according to the various nature, strength, and shape of the magnet, as well as of the iron.

Magnetic attraction takes place between the magnet and such ferruginous bodies as were not magnetic before, or between the contrary poles of two magnets: but when

two magnets are placed with their poles of the same name toward each other, then, instead of attracting, they repel each other. However, it often happens, that though the north pole of one magnet be placed near the north pole of another magnet, or the south pole of the one be placed near the south pole of the other, yet they attract each other: and sometimes they shew no attraction nor repulsion.

In order to reconcile this apparent contradiction, it is necessary to mention first another phenomenon, which takes place whenever a piece of ferruginous substance is brought near a magnet; and which indeed is the foundation of, and serves to explain, a great many other appearances, otherwise unintelligible, in the science of magnetism.

The phenomenon, in short, is this: *viz.* When a piece of iron, or any other substance that contains iron, is brought within a certain distance of a magnet, it becomes itself a magnet, having the poles, the attractive power, and in short every property of a real magnet. That part of it

which

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which is nearest to the magnet, acquires a contrary polarity : thus, if an oblong piece of iron, A B, be brought within a proper distance of a magnet, so that the extremity A of the iron may be opposite the north pole of the magnet, then this same extremity A will become a south pole, and the other extremity B will become a north pole.—This law will be rendered very evident by the experiments in the Third Part of this treatise.

The magnetism acquired by being placed within the influence or the sphere of activity of a magnet, in soft iron lasts only whilst the iron continues in that situation, and when removed from the vicinity of the magnet, its magnetism vanishes immediately ; but with hard iron, and especially with steel, the case is quite different ; for the harder the iron or the steel is, the more permanent is the magnetism which it acquires from the influence of a magnet ; but it will be in the same proportion difficult to render it magnetic. If, for instance, a soft piece of iron and a piece of hard steel, both of the same shape and size,

be

be brought within the influence of a magnet at the same distance, it will be found that the iron will appear much more magnetic than the steel ; but if the magnet be removed, the soft iron will instantly lose its magnetism, whereas the hard steel will preserve it for a long time.

From these observations two consequences are evidently deduced, *viz.* first, that there is no magnetic attraction but between the contrary poles of two magnets ; for the iron, or other ferruginous body, that is presented to a magnet, must become itself a magnet before it be attracted : and secondly, it appears why a magnet must attract a piece of soft iron more forcibly than hard iron, and much more than hard steel, *viz.* because the hard iron, and more especially the hard steel, does not become so strongly magnetical as soft iron, when presented to a magnet.

We may now resume the subject of magnetic repulsion, and shew why the magnetic poles of the same name may repel, attract, or not act at all upon one another.

Indeed,

Indeed, the law of repulsion being always exerted between magnetic poles of the same name, nearly as strong as the attraction between those of different name, remains certain and immutable; but it often happens, that one of the magnets, being more powerful than the other, will change the pole of that other magnet, in the same manner as it gives magnetism to any other piece of iron which is exposed to its influence, and then an attraction will take place apparently between magnetic poles of the same names; though in fact it is an attraction between poles of different name, because one of them has been actually changed. Thus, suppose that a powerful magnet be placed with its north pole very near the north pole of a weak magnet; it will be found that instead of repelling they will attract each other, because that part of the weak magnet, which before was a north pole, has been changed into a south pole by the action of the strong magnet.

As those bodies which are possessed of any magnetism cannot be very readily affected by the influence of another magnet,
for

for the very same cause which renders them capable of retaining any magnetism at all, namely their hardness; and, as the power of a magnet diminishes in proportion to the distances from its surface, it follows, that when the north or south pole of a weak magnet is from a considerable distance gradually brought near the like pole of a powerful magnet, the pole of the weak magnet cannot be changed very easily; hence, beyond a certain distance, *viz.* before the said pole be changed, the two magnets must exert a repulsion against each other; but when the small magnet has been brought so near the powerful one as that its pole may begin to be changed, then neither an attraction nor a repulsion will take place; and when the two magnets are approached nearer than that limit, then, the pole of the weak one being changed, an attraction will ensue.

After these observations, the ingenious reader may easily imagine that the decrease of repulsion between homogeneous magnetic poles must be at least as much if not more irregular than the decrease of the at-

Dtraction

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traction at different distances. It is likewise evident, that many objects must be had in view in attempting to investigate the law of that decrease.

Neither the attraction nor the repulsion of magnetism is sensibly affected by the interposition of bodies of any sort, except iron or ferruginous bodies in general. Thus, suppose that when a magnet is placed at an inch distance from a piece of iron, there is required an ounce of force to remove it; or, which is the same thing, suppose that the attraction towards each other is equal to one ounce; it will be found that the said degree of attraction remains constantly unaltered, *viz.* always equal to one ounce, though a plate of other metal, or of glass, or paper, or other body, be interposed between the magnet and the iron, or though they be inclosed in separate boxes of glass or other matter. Neither the absence or presence of air has any effect upon them. In short, no other substance besides iron, or those bodies which contain that metal in any of its metallic states, does sensibly affect the attraction or repulsion of magnetism.

Heat weakens the power of a magnet; and a white heat destroys it entirely, or at least in a great measure. Hence it appears, that from this cause alone, besides others which may concur, the power of a magnet must be continually varying.

The attractive power of a magnet may be increased considerably by gradually adding more and more weight to it; for by this means it will be found that the magnet will keep suspended on one day a little more weight than it did the preceding day; which additional weight being added to it on the following day, or some time after, it, will be found that the magnet can keep suspended a weight still greater, and so on as far as a certain limit.

On the contrary, by an improper situation, or putting a very small weight of iron to it, the magnet may gradually lose much of its strength.

It has been said by various authors, that in these northern parts of the world the north pole of a magnet generally has an attractive power somewhat stronger than the south pole, but in the southern parts of

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the earth the south pole of the magnet is said to possess the greatest attractive power. This law, however, has not been yet properly ascertained.

The holding of a piece of iron of some magnitude to one pole of a magnet, increases the attraction of the other pole, so as to enable it to lift a greater weight.

It has been observed, that amongst the natural magnets, the smallest generally possess a greater attractive power, in proportion to their size, than those which are larger. There have been often seen natural magnets, not exceeding the weight of 20 or 30 grains, which could lift a piece of iron that weighed 40 or 50 times more than themselves. Mention is made of a small magnet wore in a ring, which weighed about three grains, and was capable of taking up 746 grains, or nearly 250 times its own weight; and I have seen one which could not weigh more than six or seven grains, and was capable of lifting a weight of about 300 grains. But magnets of above two pounds weight, seldom lift up 10 times their own weight of iron.

It

It often happens, that a natural magnet, cut off from a larger load-stone, will itself be capable of lifting a greater weight of iron than the original large load-stone from which it was cut off. This must be imputed to the heterogeneous nature of the large load-stone; for, suppose that one part of it contains a good quantity of pure metal strongly magnetical, the rest of it being impure, or mixed with other substances, it is plain that the impure part can only obstruct the action of the purer part; hence this latter, being separated from the rest, must act more powerfully than the whole together did.

As both magnetic poles together attract a much greater weight than a single one, and as the two poles of a magnet are generally in opposite parts of its surface, in which situation it is almost impossible to adapt the same piece of iron to them both at the same time; therefore it has been commonly practised to adapt two broad pieces of soft iron to the poles of a load-stone, and to let them project on one side of the magnet, because in that case, the pieces of iron being rendered themselves

magnetic, another piece of iron could be conveniently adapted to their projections, so as to let both poles act at the same time. Those pieces of iron are generally held fast upon the magnet by means of a brass or silver box. The magnet in this case is said to be *armed*, and the pieces of iron are called the *armature*.

In fig. 1st of plate I. A B represents the magnet; C D, C D represent the armature or pieces of iron, the projections of which are D D, and to which the piece of iron F is made to adhere. The dots E C D C D represent the brass box, having a ring E at its upper part, by which the armed magnet may be suspended. Thus the two poles of the magnet, which are at A and B, are made to act at D D, where the straight piece of iron F may be conveniently applied.

For this purpose, and to avoid the armature, artificial magnets have been made in the shape of a horse-shoe, having their poles in the truncated extremities; for which reason they have more power than the straight magnetic bars.

C H A P. IV.

Of the Magnet's directive property, or polarity.

IT is an invariable law in magnetics, that no magnet is without a south and a north pole; but it often happens, that the same magnet has more than two poles, *viz.* some of one name, and some of the other. The figure, and also the heterogeneous nature of the magnets, is the principal cause of their often having more than two poles. It is impossible to determine the number and situation of the poles in a magnet without actual trial; and the method of ascertaining them is, to present the various parts of the surface of the magnet in question to one of the poles of another magnet that is freely suspended; for those parts of the magnet, which repel the other suspended one, have the same polarity, and those, which attract it, have a different polarity. For instance, if the magnet be presented to the north pole of

the other suspended magnet, then those parts of the former which repel the latter are possessed of a north polarity; and those, which attract it, are possessed of a south polarity.

Two laws may be remarked, with respect to magnets that have more than two poles. The first is, that the parts adjacent to one pole are possessed of a contrary polarity; and the second is, that the number of poles of one denomination in a magnet is either equal to, or differs from the number of poles of the other denomination by one. Thus, if the magnet has four south poles, then it will have either four, or three, or five, north poles.

Good magnets, of an uniform texture and properly shaped, have only two poles: and they lie in opposite parts of their surfaces; so that a line drawn from the one to the other passes through the centre of the magnet*.

In

* Here it must not be understood, that the polarity of a magnet resides only in two points of it; for, in truth, it is the half, or a great part of the magnet, that

is

In such magnets, the line between the two poles is called the *axis*; and a line formed all round the surface of the magnet by a plane, which divides the axis into two equal parts, and is perpendicular to it, is called *the equator of the magnet*. It appears, therefore, that philosophers have appropriated to the magnet the poles, the equator, and the meridian, in imitation of the terraqueous globe; but, to complete the similarity, magnets have been often made of a spherical shape, with the poles and equator marked on their surfaces. When so shaped they have been called *terrellas*, that is *small earths*.

If a magnet be broken into two or more parts, each part is a perfect magnet of itself, having two, and sometimes more poles; though not every one of the parts has always the same number of poles.

is possessed of one polarity, *viz.* has the property of repelling the contrary pole of another magnet, and the rest of the magnet is possessed of the other polarity: the poles then are those points in which that power is the strongest,

The poles of the fragments generally, but not always, answer to the poles which were nearest to them in the original magnet.

When a magnet can move itself freely, as, if it be suspended by a fine thread, or if it be made to float on water by means of a piece of wood, or if it be poised on a point, and provided it be not disturbed by the vicinity of iron, &c. it will place itself so as to direct its north pole towards the north, and the south pole towards the south. Besides, it depresses one of its poles below the horizon, at the same time that the other pole is elevated above it.—Of this latter property or inclination, we shall treat in the next chapter, and shall examine the former only in the present.

When a magnet, that is freely suspended, has only two poles, it will place itself very readily in the magnetic meridian, or in that plane in which other good magnets are wont to place themselves: but when it has more than two poles, it may happen, that those poles are so situated as that

that the magnet will not traverse, that is, it will have no directive power, and yet it will attract, repel, &c. Suppose, for instance, that an oblong magnet possesses a north polarity equally strong at each extremity, and a south polarity in the middle; it is plain, that as each of the extremities has an equal tendency towards the north, neither of them can be directed towards the north in preference to the other; consequently the magnet cannot traverse*. Indeed, when both extremities have the same polarity, it happens very seldom that they are precisely of the same strength; and therefore, excepting this case, the magnet will always traverse; however, as the case has happened sometimes naturally, and it may, though with difficulty, be effected by art, it is proper that the young experimenter be apprized of it, in order to prevent surprise and mistakes.

* It is hardly necessary to observe, that if this same magnet be broken in two pieces, the parts will traverse very readily.

The directive property of the magnet is the most wonderful, and altogether the most useful part of the subject. By it the mariners are enabled to conduct their vessels through vast oceans, out of the sight of land, in any given direction; by it the miners are guided in their works below the surface of the earth; and travellers are conducted through deserts, otherwise impassable. The usual method is, to keep an oblong piece of magnetic steel (*i. e.* an artificial magnet) suspended so as to move very freely; which will place itself always in the plane of the meridian, or not much distant from it, *viz.* with one end towards the north, and with the opposite end towards the south; then, by looking upon the direction of this magnet, or magnetic needle, they direct their course so as to make any required angle with it, *viz.* to go in any required direction with respect to the parts of the world. Thus, suppose that a vessel setting off from a certain place, must go to another place which is exactly westward of the former; in that case,

case, the vessel must be directed so that its course may be always at right angles with the situation of the magnetic needle, and so as to let the north end of the needle be on the right hand side, and the south end on the left hand side of the vessel; for, as the magnetic needle lies north and south, the direction of east and west, which is the course of the vessel, is exactly perpendicular to it.—A little reflection will easily shew how the vessel may be steered in any other direction.

An artificial steel magnet fitted for this purpose, in a proper box, is called the *mariner's compass*, or *sea compass*, or simply the *compass* *.

Though

* The magnet's attractive power has been known to the remotest antiquity; it being mentioned by Homer, Pythagoras, Aristotle, Plato, and others. The Jews were acquainted with it. See Kircher *de magnete*, lib. i. cap. v. But the earliest knowledge of its directive property, or the discovery of the use of the magnetic needle in Europe, was not known before the 13th century.

Th

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Though the north pole of the magnet, in every part of the world, is directed nearly towards the north, yet it happens very seldom that it points exactly towards it, and, of course, that the south pole of the magnet

The honour of this invention has been much contended for; but by the consent of most writers it seems, that a certain Flavio or John de Gioja, or Giova, or Gira, a Neapolitan, who lived in the 13th century, has the best title to the discovery. Dr. Gilbert, an English writer of the 16th century, in his book *de magnete*, affirms, that Paulus Venetus brought the invention of the compass to Italy in the year 1260; having learned it of the Chinese. Ludi Vertomanus asserts, that when he was in the East-Indies, about the year 1500, he saw a pilot direct his course by a magnetic needle fastened and formed like those now in use. And Mr. Barlow, in his Navigator's Supply, anno 1597, relates, that in a personal conference with two East-Indians, they affirmed, that, instead of our compass, they used a magnetic needle of about six inches in length, suspended upon a pin in a dish of white china earth filled with water, in the bottom of which there were marked two cross lines to indicate the principal winds; the rest of the divisions being left to the skill of their pilots. But these two last observations, being of a date much posterior to the use of the magnetic needle in Europe, conclude nothing with respect to its original discovery; since the use of that

magnet points exactly towards the south. In other words, the magnetic meridian does seldom coincide with the meridian of the place, and generally declines a few degrees eastward or westward of it. This declination is different in different places,

on

that magnetic property might have been introduced into Asia by some European.

P. Duhalde, in his General History of China, vol. i. in the annals of the Chinese monarchy, speaking of the Emperor *Hoangti*, when he gave battle to *Tchi Yeou*, says, "He perceiving that thick fogs saved the enemy from his pursuit, and that the soldiers rambled out of the way, and lost the course of the wind, he made a carr, which shewed them the four cardinal points: by this method he overtook *Tchi Yeou*, made him prisoner, and put him to death. Some say there were engraved in this carr, on a plate, the characters of a rat and a horse, and underneath was placed a needle to determine the four parts of the world. This would amount to the use of the compass, or something very near it, being of great antiquity and well attested."

And, in another part of the same book, speaking of certain ambassadors, says, "After they had their audience of leave, in order to return to their own country, *Tcheou Kong* gave them an instrument, which on one side pointed towards the north, and on the opposite

site

on land as well as at sea ; and is also continually varying in the same places. For instance, the declination in London is not the same as at Paris, or as at the Cape of Good Hope ; and the declination in London, or at some other place, is not the same now

" site side towards the south, to direct them better on
 " their way home, than they had been directed in
 " coming to China. This instrument was called
 " *Tchi Nan*, which is the same name as the Chinese
 " now call the sea compass by : This has given oc-
 " casion to think, that *Tcheou Kong* was the inventor
 " of the compass."—This happened in the 22d cycle,
 above 1040 years before Christ.

Renaudot adduces strong reasons against the knowledge of the mariner's compass amongst the ancient people of China, and of Arabia. See Kircher *de magnete*, lib. i. cap. v.

Sir G. Wheeler says, that he had seen a book of astronomy older than the year 1302, which mentions the use of the needle in astronomy, but not in navigation. And in an old French poet, named Guyot de Provins, who wrote about the year 1180, there is express mention made of the load-stone and the compass ; but their use in navigation is obliquely hinted at.

The Spanish jesuit Pineda, and Kircher, affirm that Solomon knew the use of the compass, and that his subjects did actually use it in their navigations.

Notwith-

now as it was 20 years ago, or some time ago. The change or variation of the declination may be observed even in one hour's time; or, more properly speaking, the magnetic meridian, in one and the same part of the world, is continually shifting its situation.

This variation cannot be owing to any imperfection in the construction of the magnetic needles, or to the various strength of different magnets, because all the magnets or magnetic needles, that are kept in the same place, shew exactly the same declination, provided they be freely suspended, and not placed within the influence of each other, or of other ferruginous bodies *.

The

Notwithstanding the foregoing remarks, it is still very doubtful whether the use of the compass in navigation, or even the traversing property of the load-stone, was known by any people before the Europeans began to use it, in or about the 13th century; in which time the above-mentioned Flavio, or John de Gioa, if not the inventor, was at least the first who used it for the guidance of vessels in the Mediterranean.

* The discovery of the declination of the magnetic needle is generally attributed to Sebastian Cabot, a Venetian, who is said to have discovered it in the year

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The uncertainty of this declination in different parts of the world, is one of the greatest impediments against the perfection of navigation; and therefore philosophers have spared no pains in endeavouring to investigate its cause, and, if possible, to correct the errors that necessarily arise from it; but human industry has not yet been able to elucidate this obscure part of the subject of magnetism.

Ever since the discovery of the declination of the magnetic needle, ingenious persons, both at sea and on land, have assiduously endeavoured to ascertain its quantity in different places; and their observations have been not only registered in books, but are also set down in good sea charts, for the use of future navigators: however, those observations can serve for a few years only, on account of their being

1500; though in truth it was Columbus who, as is mentioned in his life, discovered it, in his first voyage to America in 1492; but the variation of the declination, or the variation of the declination in the same place, but at different times, was discovered by Mr. Gellibrand, a professor in Gresham College, about the year 1625.

inconstant

inconstant and fluctuating in the same places; nor has it yet been discovered that this variation or fluctuation is subject to any law or period; though various hypotheses have been framed for its explanation.

When the compilation of the present work was first begun, my design was to insert in it all the observations relating to the declination of the magnetic needle, which had been made in different parts of the world, and at different times, for the use of those persons who might wish to investigate the cause or period of that variation; but, after having extracted the observations of divers navigators and other observers from the accounts of voyages, &c. it appeared that the bulk of those observations alone, independent of any other part of the subject, would require a volume larger than the present. Considering, therefore, that this additional volume could be of use only to a few speculative persons (and probably it would not be productive of any useful theory; since, as will be particularly mentioned in the sequel, the cause,

upon which the declination and its variation are likely to depend, seems to be itself very fluctuating and irregular) I have contented myself with subjoining only a list of a few observations made in various parts of the world, together with the observations made at different times in London. After which I shall conclude this chapter with some general observations relating to the declination, and a specimen of the daily variation.

N. B. By the declination being east or west, is meant, that the north extremity of the magnetic needle is on the eastern or western side of the meridian of the place.

Latitude, North. ° '	Longitude, West. ° '		Declination, East. ° '		Years in which the observations were made.
	°	'	°	'	
70. 17.	163. 24.		30. 21.		1779.
69. 38.	164. 11.		31. 0.		1778.
66. 36.	167. 55.		27. 50.		
65. 43.	170. 34		27. 58.		
63. 58.	165. 48.		26. 25.		
59. 39.	149. 8.		22. 54.		
58. 14.	139. 19.		24. 40.		
55. 12.	135. 0.		23. 29.		
53. 37.	134. 53.		20. 32.		

Latitude.

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Latitude, North.		Longitude, West.		Declination, West.		Years in which the observations were made.
°	'	°	'	°	'	
50.	8.	4.	40.	20.	36.	1776.
48.	44.	5.	0.	22.	38.	
40.	41.	11.	10.	22.	27.	
33.	45.	14.	50.	18.	7.	
31.	8.	15.	30.	17.	43.	
28.	30.	17.	0.	14.	0.	
23.	54.	18.	20.	15.	4.	
20.	30.	20.	3.	14.	35.	
19.	45.	20.	39.	13.	11.	
16.	37.	22.	50.	10.	33.	
15.	25.	23.	36.	9.	15.	
13.	32.	23.	45.	9.	25.	
12.	21.	23.	54.	9.	48.	
11.	51.	24.	5.	8.	19.	
8.	55.	22.	50.	8.	58.	
6.	29.	20.	5.	9.	44.	
4.	23.	21.	2.	9.	1.	
3.	45.	22.	34.	8.	27.	
2.	40.	24.	10.	7.	42.	
1.	14.	26.	2.	5.	35.	
0.	51.	27.	10.	4.	59.	
0.	7.	27.	0.	4.	27.	
South.						
1.	13.	28.	58.	3.	12.	
2.	48.	29.	37.	2.	52.	
3.	37.	30.	14.	2.	14.	
4.	22.	30.	29.	2.	54.	
5.	0.	31.	40.	1.	26.	
6.	0.	32.	50.	0.	6.	

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Latitude, South.	Longitude, West.	Declination, East.	Years in which the observations were made.
°	'	°	'
6. 45.	33. 30.	00. 35. West.	1776.
7. 50.	34. 20.	00. 7.	
8. 43.	34. 20.	00. 15. East.	
9. 1.	34. 50.	00. 44. West.	
10. 4.	34. 49.	00. 38. East.	
12. 40.	34. 49.	1. 12.	
13. 23.	34. 49.	1. 1.	
14. 11.	34. 49.	1. 9.	
15. 33.	34. 40.	1. 15.	
16. 12.	35. 20.	2. 4.	
18. 30.	35. 50.	3. 2.	
20. 8.	36. 1.	5. 26.	
21. 37.	36. 9.	3. 24.	
24. 17.	36. 8.	3. 24.	
26. 47.	34. 27.	3. 44.	
28. 19.	32. 20.	1. 58.	
30. 25.	26. 28.	2. 37. West.	
33. 43.	16. 30.	4. 44.	
35. 37.	9. 30.	5. 51.	
38. 52.	23. 20. East.	22. 12. East.	
40. 36.	173. 34.	13. 47.	
42. 4.	167. 32.	13. 17. West.	
44. 52.	155. 47.	9. 28.	
46. 15.	144. 50.	14. 48.	
48. 41.	69. 10.	27. 39.	

Declination observed in London at different times.

Years.	Declination.		When
	°	'	
1576.	11.	15.	
1580.	11.	11.	
1612.	6.	10.	
1622.	6.	0.	
1633.	4.	5.	
1634.	4.	5.	
1657.	0.	0.	
1665.	1.	22 $\frac{1}{2}$.	
1666.	1.	35 $\frac{1}{2}$.	
1672.	2.	30.	
1683.	4.	30.	
1692.	6.	0.	
1700.	8.	0.	
1717.	10.	42.	
1724.	11.	45.	
1725.	11.	56.	
1730.	13.	00.	West.
1735.	14.	16.	
1740.	15.	40.	
1745.	16.	53.	
1750.	17.	54.	
1760.	19.	12.	
1765.	20.	00.	
1770.	20.	35.	
1774.	21.	3.	
1775.	21.	30.	
1780.		.	
1785.		.	

When the variation of the magnetic needle was first discovered, it was to the east of the meridian of London, and of several other places on the continent. It has been since that time advancing continually towards the west, so that in the year 1657, the magnetic needle pointed due north and south ; and, at present, its variation is about 22° west. This gradual advance of the needle's variation from the east to the west, has been observed in various other places ; but in some parts of the world the variation has neither moved with the same celerity, nor towards the same way. The rate of its increase has neither been very regular, *viz.* if the variation increased was 10 minutes in one year, it did not keep constantly increasing 10 minutes more for every subsequent year ; though sometimes it has shewn a considerable degree of regularity for a few years. In short, the observations and theories hitherto made, relating to the variation of the magnetic needle, do not point out any way, by which the declination in a given place, and for a given time, may be foretold with any degree of certainty.

The

The daily variation is evidently affected by the heat and cold ; though their not being always proportionate to each other, shews, that heat is not the only cause upon which it depends.

I shall now add, as a specimen of the daily variation, the observations made at different hours of one and the same day, and also, the mean variation for each month in the year, according to the observations of the late ingenious Mr. Canton *.

* Phil. Trans. vol. li.—If the reader be desirous of examining farther the observations made concerning the variations of different places, and at different times, he may consult the Phil. Trans.—the History de l'Academie de Paris—almost all the Acts of other academies—the observations made in the course of Capt. Cook's voyages, and published by Mr. Bayly and Mr. Wales.—&c. &c.

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The declination observed at different hours of the same day.

June 27th, 1759.

	Hours.	Minutes.	Declination West.	Degrees of Fahrenheit's thermometer.
Morning.	0.	18.	12. 2.	62.
	6.	4.	18. 58.	62.
	8.	30.	18. 55.	65.
	9.	2.	18. 54.	67.
	10.	20.	18. 57.	69.
	11.	40.	19. 4.	68 $\frac{1}{2}$.
Afternoon.	0.	50.	19. 9.	70.
	1.	38.	19. 8.	70.
	3.	10.	19. 8.	68.
	7.	20.	18. 59.	61.
	9.	12.	19. 6.	59.
	11.	40.	18. 51.	57 $\frac{1}{2}$.

The mean variation for each month in the year.

			,	"
January	—	—	7.	8.
February	—	—	8.	58.
March	—	—	11.	17.
April	—	—	12.	26.
May	—	—	13.	0.
June	—	—	13.	21.
July	—	—	13.	14.
August	—	—	12.	19.
September	—	—	11.	43.
October	—	—	10.	36.
November	—	—	8.	9.
December	—	—	6.	58.

C H A P-

CHAPTER V.

Of the magnet's inclination, or dipping needle.

TAKE a globular magnet, or, which is more easily procured, an oblong one, like S N, fig. 2. of plate I; the extremity N of which is the north pole, the other extremity S, the south pole, and A is its middle or equator. Place it horizontally upon a table C D; then take another small oblong magnet n s (a common small sewing needle, made magnetic, answers perfectly well for this purpose), and suspend it, by means of a fine thread tied to its middle, in such a manner as to remain in a horizontal position, when not disturbed by another magnet, &c. Now, if the said small magnet, being held by the upper part of the thread, be brought just over the middle of the large magnet, within two or three inches of it, you will find, that this small magnet will turn itself so as to direct its south pole s towards the north pole N of the large magnet, and its

its north pole n towards the south pole S of the large one ; agreeably to the magnetical law mentioned in the preceding pages, *viz.* that poles of different name attract each other. It will be farther observed, that the small magnet, whilst kept just over the middle A of the large one, will remain parallel to it, and consequently in a horizontal situation ; the reason of which is, because the poles of the small magnet, being equally distant from the contrary poles of the large one, are equally attracted. But if the small magnet be moved a little nearer to one end than to the other of the large magnet, then one of its poles, namely that which is nearest to the contrary pole of the large magnet, will be inclined downwards ; and of course the other pole will be elevated above the horizon. It is evident that this inclination must be greater according as the small magnet is placed nearer to one of the poles of the large magnet, because the attraction of the nearest pole will have more power upon it. Farther, if the small magnet be brought just opposite

one of the poles of the other, it will turn the contrary pole towards it, and will place itself in the same straight line with the axis of the large magnet.—

Observe the fig.

After comprehending this very easy experiment, the reader, in order to understand the phenomena of the magnetic inclination or dipping needle upon the surface of the earth, needs only imagine that the earth is the large magnet, and that the magnetic needle, or any other magnet, is the small magnet of the preceding experiment; for, admitting that the north pole of the earth is possessed of a south magnetic polarity, and that the opposite pole is possessed of a north magnetic polarity, it appears, as is confirmed by actual experience, that when a magnet, properly shaped and suspended, is kept near the equator of the earth, it must remain in a horizontal situation; that if it be removed nearer to one of the poles of the earth, it must incline one of its extremities, namely that which is possessed of the contrary magnetic polarity;

rity ; that the said inclination must increase in proportion as the magnet or magnetic needle recedes from the equator of the earth ; and lastly, that when brought just upon either of the poles of the earth, it must stand perpendicular to the ground, *viz.* in the same straight line with the axis of the earth. The direction of the dipping needle, in any place, is called the *magnetical line*.

My reader must not be surprised to hear, that a south magnetism is attributed to the north pole of the earth ; it being only meant, that it has a magnetic polarity contrary to that end of the magnetic needle which is directed towards it ; and, as we call that same end of the needle a north magnetic pole, we must of necessity attribute a contrary polarity, that is, a south magnetic polarity, to the north pole of the earth. With a proper change of names, the same remark must be understood of the south pole of the earth, which therefore must be considered to be possessed of a north magnetic polarity.

That the whole body of the earth acts like a real

a real magnet, is a supposition, not only suggested by the similarity between the phenomena of the dipping needle and the above-mentioned experiment; but is confirmed by many other experiments and observations, so that it would be scepticism indeed to doubt of it: we shall, however, examine this subject more at large in the next Part.

If the poles of the earth, *viz.* the extremities of the axis, about which it performs the diurnal rotation, coincided with its magnetic poles, or even if the magnetic poles were always at a fixed distance from them, the inclination of the magnetic needle would be regular, and navigators could derive great advantage from it; for it would not be difficult to determine, by mathematical means, the degree of the inclination of the needle in any given latitude; and consequently, by observing the actual inclination of the dipping needle in any required place, the mariners could thereby ascertain the latitude of that place. The case, however, is far different; for the magnetic poles of

the

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the earth are continually shifting situation; and that without any known regularity or period: hence, the inclination, as well as the horizontal direction, of the needle is continually changing in the same place, and generally it changes very little in one place, and a great deal or nothing in another; so that the exact degree of its inclination, in any given place, can only be ascertained by actual experiment.—Here follow a few observations of the inclination of the needle in various places.

Latitude, North. ° '	Longitude, East. ° '	The north end of the needle below the horizon. ° '	Years in which the observa- tions were made.
53. 55.	193. 39.	69. 10.	1778.
49. 36.	233. 10. <small>West.</small>	72. 29.	
44. 5.	8. 10.	71. 34.	1776.
38. 53.	12. 1.	70. 30.	
34. 57.	14. 8.	66. 12.	
29. 18.	16. 7.	62. 17.	
24. 24.	18. 11.	59. 0.	
20. 47.	19. 36.	56. 15.	
15. 8.	23. 38.	51. 0.	
12. 1.	23. 35.	48. 26.	
10. 0.	22. 52.	44. 12.	
5. 2. <small>South.</small>	20. 10.	37. 25.	
0. 3.	27. 38.	30. 3.	

Latitude,

Latitude, South.	Longitude, East.	The north end of the needle below the horizon.	Years in which the observations were made.
°	'	°	'
4. 40.	30. 34.	22. 15.	1776.
7. 3.	33. 21.	17. 57.	
11. 25.	34. 24.	9. 15. South end be- low.	
16. 45.	208. 12.	29. 28.	
19. 28.	204. 11.	41. 0.	
21. 8.	185. 0.	39. 1.	1777.
35. 55.	18. 20.	45. 37.	1774.
41. 5.	174. 13.	63. 49.	1777.
45. 47.	166. 18.	70. 5.	1773.

Two principal observations may be made with respect to the dipping needle: the first is, that its inclination does not alter regularly in going from north to south, or from the latter to the former, along any meridian; and the second is, that its alteration in the same place, at different times, is very small: Thus, in London, about the year 1576, the north pole of the dipping needle stood $71^{\circ}. 50'$. below the horizon; and in the year 1775 it stood at $72^{\circ}. 3'$, the alteration of the inclination in so many years amounting to less than a quarter of a degree, which may

be even attributed to the error of the instruments, since, as will appear in the sequel, those instruments are far from having attained to any perfection, even in the present age.

CHAPTER VI.

Of the various bodies which are attracted by the magnet.

PROPERLY speaking, the magnet attracts only iron, in whatever state that metal may be; but, as most natural bodies contain too small a quantity of iron to be called ferruginous, and yet they are attracted by the magnet, it is proper to enumerate them in this chapter, not only to shew the great dispersion of iron throughout the works of nature, but also, because those observations seem likely to open the way to farther discoveries in other branches of philosophy as well as magnetism.

The list of those bodies is very comprehensive;

prehensive; there being hardly any substance, but which, if not naturally, at least by subjecting it to the action of fire, may be rendered, in some measure, capable of being attracted by the magnet.

Iron is attracted with different degrees of force, according to the different states of its existence; but it never becomes quite insensible to the magnetic power. Even the purest calx, or the compleatest solution, that has been produced of that metal, when properly examined, is found to be in some degree attracted by the magnet.

Soft iron, clean and of an uniform texture, is attracted more forcibly than the hard, or any other sort of iron. Steel, especially when hardened, is attracted much less forcibly than iron. The scales which are separated from the surface of red-hot iron when hammered, and the particles of burned steel that are produced from the collision of a flint and steel, are attracted by the magnet about as well as pieces of good iron that equal them in bulk.

The black calx of iron is attracted very

weakly. The red calx, or rust, whether it be produced by the action of acids, of fire, or of exposure to the atmosphere, is attracted very little; but it never becomes quite insensible of the magnet's action, though it be repeatedly washed and purified.

When the particles of iron are in the form of black scales, or even in that of red calx, they are often of such a nature, perhaps owing to their hardness, as to acquire a weak but sensible polarity from the influence of a strong magnet; so that, by changing the pole of the magnet that is presented to them, they may be made to turn accordingly; though, in general, they are attracted alike on every side.

Besides the different states of purity, the attraction between the iron and a magnet is subject to a considerable variation, arising from the size of the iron; for a single piece of iron of a certain bulk, which, as was observed in the 3d chapter, must be determined by experiment in any magnet, is attracted more forcibly than either a larger or a smaller piece, or than many pieces,

pieces, which, taken all together, are equal to it in weight ; hence it follows, that a quantity of iron is attracted with the least force, when reduced into the smallest bits, or finest powder.

The ores of iron are attracted more or less readily, according as they contain a greater or smaller quantity of metal, and as that metal is in a more or less perfect metallic state ; but they are always attracted, even those which contain so small a quantity of metal as hardly to deserve the name of ores.

By the action of fire, the iron ores are generally put in a state of being much more readily attracted, which is evidently owing to their acquiring more of the inflammable principle, or to their approaching nearer to the perfect metallic state. In fact, if those ores which are very weakly attracted, be exposed to the action of fire, when they are surrounded by substances that abound with the inflammable principle, they are thereby rendered much more capable of being attracted, than if they be

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exposed to an open fire, and to the current of air, by themselves.

The ores of other metals are generally, though weakly, attracted by the magnet, which shews their containing some iron ; such are the ores of lead, of tin, and of copper. Native cinnabar is likewise attracted ; but the factitious cinnabar is not *.

The pure metals are not attracted ; and it is very singular, that though pure lead is not attracted in the least by the magnet, yet its calx is a little attracted. The calx of tin is likewise attracted, but even in a smaller degree †.

Of the semi-metals, zinc, bismuth, and particularly cobalt, as well as their ores, are almost always attracted by the magnet. Antimony is not attracted unless it be first exposed to a gentle fire. Arsenic is not attracted at all.

* This remark shews, that the colour of a mineral is not always a sure indication of its containing iron ; for both sorts of cinnabar have the same red colour.

† See Brugman de affinit. magnet. § xxxix.

A certain

A certain sort of bismuth is said to possess a very singular property, which is, that the magnet repels it on every side *.

Whoever considers the vast dispersion of iron throughout the world, and its being always capable of attraction towards the magnet, will easily believe, that there is hardly any substance in nature, which, if not in its usual state, at least by burning, may be rendered capable of being in some measure attracted by the magnet.

The other minerals besides the metallic, are almost all attracted by the magnet, at least after having been exposed to the action

* “ Bismutum colore albo, argenteo, nitente, trahitur a magnete, crescitque illius attractio ex igne semimetallum hoc in calces vertente; sed bismutum cuius colori magis obscuro quid de violaceo inhærebat singulare admodum phænomenon exhibuit. Ejus scilicet portio, circello chartaceo aquæ innatanti immissa lente, ab utroque magnetis polo in omnem plagam repellebatur. Huic simile quid me semel tantum, et casu, inter millena experientia magnetica, observasse memini, in molecula exigua ex lapide nostro molari excussa. Repulsio hæc bismuti singularis in attractionem ignis operatur mutatur perquam tamen continuo exiguum.”
Brugman de affinit. magnet. § xl.

of fire *. Of the pure earths, the calcareous is least or not at all, and the siliceous the most frequently, attracted. Sand is generally attracted, especially the black sea-sand, which evidently contains a good deal of martial earth, or rather half-formed iron.

Amber and other combustible minerals are generally attracted by the magnet, especially after burning.

Of the precious stones, those which are pellucid, as the diamond, and crystals, are not attracted. The amethyst, topaz, chalcedony, and generally those which are de-

* When substances are to be burned, or, as it is called by several mineralogists, are to be roasted, for the sake of rendering them more easily capable of being attracted ; it has been recommended by various ingenious persons, to surround them with what they call a *reducing flux*, *viz.* with substances that contain abundance of phlogiston, in order to revivify, as much as possible, the small quantity of iron calx which is in the substances to be examined ; but care should be had, that, in this operation, some quantity of iron be not imparted to those substances by the reducing flux itself.—A common earthen crucible, though itself magnetic, yet it has been found that it imparts no iron to the substances that are exposed in it to the fire.

prived of their colour by fire, are not attracted. The other precious stones are all attracted; *viz.* the ruby, especially the oriental, the chrysolite, and the tourmalins. The emerald, and particularly the garnet, are not only attracted, but frequently acquire an evident polarity from the influence of a strong magnet, so that afterwards they are attracted from one side and repelled from the other. The opal is but weakly attracted.

Almost every part of animal or vegetable bodies, after combustion, is in great measure attracted by the magnet. The flesh, and especially the blood, after burning, are attracted most, but the bones are attracted less powerfully. The vegetables, after burning, are almost all, though not all with equal force, attracted by the magnet. But unburned and fresh animal or vegetable substances very seldom, if ever, shew any perceptible attraction towards the magnet.

It is very remarkable, that even foot, and the dust which usually falls upon whatever is left exposed to the atmosphere, are sensibly attracted by the magnet.

Thus

Thus it appears that iron, though divided into exceedingly small particles, is in some state or other mixed with every substance; that it is to be found in animals, in vegetables, in minerals, and even in the air; that in every state of existence it always shews some attraction towards the magnet; and that its existence in several substances can be discovered by no other known method besides the magnet. But a judicious enquirer might ask, Why must we conclude that a substance contains iron, only because it is in some measure attracted by the magnet? and when he is told, that the magnet attracts only iron, he might again ask for a demonstration of that law.—Indeed it seems almost certain, that some bodies, independent of iron, are attracted by the magnet; but, as the proofs of this assertion depend upon some of the author's own experiments, which will be related in the last Part of this work; it seems not proper to admit the above-mentioned assertion as a law in this place.

CHAPTER VII.

Of communicated Magnetism.

WHEN a piece of iron or steel, or, in short, of any ferruginous body, is presented to a magnet, within a proper distance of one of its poles, it becomes instantly magnetic, the part of it, which is nearest to the magnet, acquiring the contrary polarity, &c.

This acquired magnetism is strongest with soft iron, and weakest with hardened steel, or with the brittle sort of cast iron; the other sorts of iron or ferruginous bodies acquiring a stronger or weaker power, according as they approach the hardness of the latter or the softness of the former. But the permanency of the acquired magnetism follows just the reverse of this rule; so that the hardest steel retains it for many years with little or no diminution; whereas very soft iron loses it entirely the moment it is removed from the influence of the magnet; the other ferruginous bodies preserving it for a lon-

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ger or shorter time, according as they participate more of the nature of hard steel, or of that of soft iron. Hence it may be deduced, that, in general, the best method of making artificial magnets, consists in applying one or more powerful magnets to pieces of the hardest steel, because those pieces will thereby acquire a considerable power, and will retain it for a long time; taking care, in this operation, that the north pole of the magnet or magnets be applied to that extremity of the piece of steel which is required to be made the south pole, and that the south pole of the magnet be applied to the opposite extremity.—In the same manner as a piece of steel or iron is rendered magnetic, a weak magnet may be rendered more powerful, or its power may be restored when lost.

It is evident, that in this method the operator should have one or more magnets, by the application of which the steel, or other ferruginous body, may be rendered magnetical; therefore it may be asked, By what means is magnetism originally given, to such artificial magnets as are said to have that

that power imparted without the interference of any magnet?—The answer to this question is, that no magnetism at all can be communicated to any ferruginous body whatever, without the action of another magnet; and that, in the method vulgarly called, of giving magnetism to steel, &c. without the aid of a magnet, the beginning of the magnetic power is communicated from the earth, which is a real magnet; and therefore there is no magnetism communicated but by the action of another magnet.

The experiment which shews the magnetism of the earth in the clearest manner possible, and by which means the beginning of that power is communicated in the above-mentioned method, is the following :

Take a straight bar of soft iron (one of two or three feet in length, and about three quarters of an inch in diameter, will answer perfectly well), and, in these parts of the world, if you keep it in a vertical position, that is, with one end A towards the ground, and with the other end B upwards, you

you will find that the bar is magnetic; the extremity A being a north pole, capable of repelling the north pole of a magnetic needle, and the upper end B being a south pole, capable of repelling the south pole, and of attracting the north pole, of the magnetic needle.—If you invert the bar, placing it with the extremity B downwards, its polarity will be instantly reversed, B becoming the north, and A the south pole*. The explanation of this curious phenomenon is easily deduced from the foregoing observations; for, since in these northern parts the earth is possessed of a south magnetic polarity, the lowest part of the iron bar, by being nearest to it, must acquire the contrary, namely the north polarity; the other extremity of the bar becoming a south pole.

It follows likewise (and it is confirmed by actual experiment) that in the southern parts of the earth the lowest part of the bar

* An iron bar of four or five feet in length, and above an inch thick, in this situation, will be capable of attracting a small bit of iron, or a common sewing-needle.

acquires

acquires the south polarity ; that on the equator the bar must be kept horizontal, in order to let it acquire any magnetism from the earth ; and that, even in these parts of the earth, the most advantageous situation of the bar is not the perpendicular, but that a little inclined to the horizon. In short, in every part of the world it must be placed in the magnetical line, *viz.* in the direction of the dipping needle *.—If the iron bar, instead of being kept in the magnetical line, be placed in a direction perpendicular to it, then it will acquire no magnetism, because in that situation the actions of both poles of the earth upon each extremity of the bar are equal. If, instead of the above-mentioned two directions, the bar be placed in any other position, then it will acquire more or less magnetic power, according as it approaches nearer to the former or to the latter of the said two directions.

A bar of hard steel, or of hard iron, does not acquire any magnetism from

* See the fifth chapter of this Part.

the earth, like the bar of soft iron, because the magnetic power of the earth is weak, in proportion to that which is required in order to render a steel bar magnetic.

Having thus described the general phenomena of communicated magnetism, we must now proceed to enumerate the particular laws, which have been ascertained concerning them.

A magnet, by communicating magnetism to other substances, not only loses nothing of its power, but has it rather improved.

A magnet can never communicate a greater power than itself possesses, or even an equal degree of it; but several magnets, of nearly an equal degree of magnetism, when joined together, have a stronger power than one of them singly; hence, in order to impart a strong magnetic power to a given body A, by means of a weak magnet B, one must first render several bodies C, D, E, F, &c. weakly magnetic, and then, by properly joining C, D, E, F, &c. together, he may communicate

municate to another body, or several other bodies, a stronger magnetism, till, at last, he will be able to communicate to A the required degree of magnetic power.

It is almost superfluous to mention, that when the ferruginous body is applied in contact with the magnet, it acquires a stronger power than if it be placed at some distance from its surface.

When a ferruginous body is exposed to the influence of a magnet, though it acquires the greatest part of the power at the very first perceptible instant; yet, in order to acquire the utmost degree, of which that body may be capable, it must remain in that influence for a considerable time. Soft iron acquires the maximum of magnetic power very readily; but, according as the nature of the ferruginous body is harder, so the maximum of the power is communicated slower.

Agreeably to those laws, it has frequently been observed, that bars, and other pieces of iron, by having remained a long time in one situation, have become mag-

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netic *. Sometimes iron bars, which were not capable of a permanent magnetism on account of their softness, have in time, and by being left exposed to the atmosphere in a due situation, acquired a considerable degree of magnetism ; but it has been also remarked, that those bars have, at the same time, become harder ; which is, perhaps, owing to a partial calcination, or to some other hitherto unascertained change in the nature of the iron.

The polarity thus communicated by the earth to iron bars, is more or less permanent, in proportion to the degree of hardness of the iron, the time of their remaining in one situation (the most proper being that of the dipping needle), and lastly, the shape of the iron, or the proportion between the thickness and length of the pieces.

An oblong piece of iron made red hot, and then left to cool in the magnetical

* It is frequently found mentioned in books, that some pieces of iron, which had remained in one situation for many centuries, were become as strongly magnetic as good natural magnets.

line, acquires thereby a degree of magnetism, which is more or less permanent, according to the nature of the iron. The reason of which is, because, whilst red hot, the iron is soft, and therefore the earth can render it magnetic more easily ; but, when cooled, it becomes harder, and consequently more tenacious of the acquired power.

In drilling, filing, hammering, and, in short, in all those cases in which iron, steel, &c. is put into violent action, some of the pieces concerned frequently acquire a considerable degree of magnetism ; the origin of which must be derived from the earth, and from the changeable nature of the metal, or the vicissitudes of heat, cold, and vibratory motion, in which it is accidentally put.

It seems that, for the same reasons, magnetism is in certain cases produced by means of electricity ; the particulars observed, concerning which, are the following, and they were ascertained by means of the most powerful electrical machine that has been yet made. — They in a

great measure, coincide with those made with other machines.

When the bar or needle is laid horizontally in the magnetic meridian, whichever way the shock of an electric jar or battery enters, the end of the bar that stands towards the north will acquire the north polarity, *viz.* the power of turning towards the north when freely suspended; the other end acquiring the south polarity. If the bar, before it receives the shock, has some polarity, and is placed with its poles contrary to the usual direction, then its original polarity is always diminished, and often reversed.

When the bar or needle is struck standing perpendicularly in these parts of the world, its lowest end becomes the north pole, even when the bar had some magnetism before, and receives the shock whilst standing with its south pole downwards. When all the other circumstances are alike, the bars seem to acquire an equal degree of magnetic power, whether they are struck whilst standing horizontally in the magnetic meridian, or perpendicular to the horizon.

When a bar or needle is placed in the magnetic equator, the shock sent through its length very seldom, if ever, renders it magnetic; but if the shock be passed through its width, then the needle becomes magnetic, the extremity of it which laid towards the west, generally becoming the north pole.

If a needle or bar strongly magnetic, or a natural magnet, be struck by the electric shock, its power is thereby diminished.

When the shock is too strong, with respect to the size of the steel needle, so as to render it considerably hot, then it acquires either none at all, or a very small degree of magnetism *.

Hence, a stroke of lightning, which is an electrical phenomenon, often renders magnetic pieces of iron, of steel, or those

* For those experiments, the bars or needles must be proportioned to the degree of electric power; otherwise, they will not succeed. See Van Marum's account of a very powerful electrical machine, constructed for the Museum of Teyler at Harlem; and my Treatise on Electricity, vol. i. p. 66. and vol. ii. p. 282.

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bodies which contain iron, as certain bricks, &c.

If one pole of a magnet, for instance the north, be applied to one end C of an oblong piece of iron or steel, like C D, fig. 3d of plate I. that end C will become a south pole; and if the bar C D be very long, there will be found a part of it, not far distant from C, which is possessed of the north polarity; and this is followed by another part, possessed of the south polarity; and so on alternately, till the power becomes imperceptible; the number of those successive poles depending upon the strength, and principally upon the length of the bar; but if the bar be of a proper length and thickness, which must be likewise proportioned to the strength of the magnet employed, then the bar will have only two poles, its other extremity D acquiring the north polarity.

In the latter case, if that pole of the magnet be gradually moved along the surface of the bar from C as far as D, it will afterwards

afterwards be found, that the polarity of the bar is entirely changed, the extremity C being now possessed of the north, and the extremity D of the south polarity.

It is evident, that, whilst the magnet is advancing along the surface of the bar, the south polarity of the end C, before it changes into a north polarity, must decrease in strength; and that when the magnet is at a certain point M, the end C has no polarity at all; its south polarity being just vanishing, and the north polarity just beginning. With respect to the extremity D, it must be observed, that its north polarity, by the approach of the magnet, is increased as far as a certain limit H; after which, as the magnet comes still nearer to D, the north polarity of this extremity decreases, till it vanishes when the magnet is arrived at a certain point N; after which its north polarity begins to be changed into a south one.

The points M and N have been called *the points of indifference*; because, when the magnet is at M, the extremity C of the bar has neither the south nor the north

polarity ; and when the magnet is at N, the end D has no polarity. The point H has been called the *culminating point*, because, when the magnet is at that point, the polarity first acquired by the end D of the bar is the strongest.

As the determination of those points, in bars of different sorts of iron, of different lengths, &c. not only shews more evidently the action of the magnet, and points out the advantages and disadvantages attending the practical methods of making artificial magnets, but is besides likely to open the way to farther discoveries ; there have been no pains spared to investigate the particulars on which their situation depends, and a vast number of accurate experiments have been made for that purpose ; but, notwithstanding those endeavours, such is the various nature of magnets, of iron, &c. that the present knowledge of the subject does not allow those points to be determined, in a given bar, without actual experiments. — The general laws which may be deduced from the various experiments made for this purpose, are the following :

i. The

1. The points M, H, and N do not come always in the order shewn by the figure; but, though their order is not always the same, yet it is evident that the point H can never coincide with, or come after N, *viz.* nearer to the end D, than the point N.

2. When the bars differ in length only, every thing else being the same, the longer the bar is (as far as a certain limit, which depends on the strength of the magnet employed) the greater is the distance CM.

3. The stronger the magnet is, which is employed, the greater is the distance CM, as far as a certain limit, which depends upon the proportion between the power of the magnet and the length of the bar; and beyond which limit CM will be shorter than if a weaker magnet had been used.

4. When the bars differ in length only, every thing else being the same, the distance CH is greater in a longer than in a shorter bar, as far as a certain limit, which depends as has been mentioned above.

5. The

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5. The stronger the magnet is which is used, the greater is the distance C H, as far as a certain limit, which depends as above.

6. In a longer bar, every thing else being the same, the distance C N is greater than in a shorter one, as far as a certain limit, &c.

7. The distance C N, in bars of equal length, is greater when a stronger than when a weaker magnet is used, as far as a certain limit, &c.

8. When the bars differ only in thickness, every thing else being the same, the distance C M is greater in thicker than in thinner bars; but the distance C N is nearly the same in them all, as far as a limit, which depends as above-mentioned.

9. Lastly, when the bars differ only in hardness, the distances C M, C H, C N, are sometimes equal, sometimes greater, and sometimes shorter, in the harder than in the softer bars *.

Besides the points of indifference and culmination, there is another point to be

* See Van Swinden's *Tentamina theoriæ mathematicæ de phænomenis magneticis.*

considered,

considered, namely, the magnetic centre, which is the point or part between the two poles, where the magnet has no attraction nor repulsion. With respect to this point, I shall briefly observe, that it does not always lie midway between the two poles; and that, when one pole of a magnet is drawn over the surface of an oblong piece of iron, as in the above-mentioned experiment, the magnetic centre moves forwards in proportion as the magnet is advanced; but at a certain limit both the magnet and the said centre are in the same place, or rather in opposite sides of the thickness of the bar. The motion and place of the magnetic centre are subject to a great deal of variety, arising from the nature, length, and thickness of the bar, as well as from the strength of the magnet, and from the manner of drawing it along the surface of the iron or other ferruginous body.

When any magnet, but especially an oblong one, having two poles, is broke in two, the magnetic centre of each part is at first generally much nearer that end of the piece

which is contiguous to the fracture ; but in time it advances nearer the centre of the piece.

What has been observed concerning oblong pieces of iron or steel, may serve to explain the phenomena which take place in pieces of an irregular form ; the particular enumeration of all which cases would be endless, and of little if at all of any use.

Every piece of iron or ferruginous body is capable of retaining only a certain degree of magnetic power ; so that if a strong magnet be applied to a comparatively small piece of steel, that piece, whilst it remains within the influence of the magnet, will appear to be very powerfully magnetic ; but as soon as it is removed from the vicinity of the magnet, its power begins to decrease, and in a short time comes down to that degree which the piece of steel is capable of, and which may be called *its point of saturation*. Hence it follows, that if a certain magnet is just sufficient to communicate to a piece of iron or steel the full power of magnetism, of which that piece

is capable, a stronger magnet will not increase it in the least.

It has been long disputed, whether a piece of iron or steel was rendered heavier or lighter by being made magnetic; but, upon the whole, it seems that its weight is not affected by it *.

As a piece of iron or steel, &c. often acquires magnetism only by standing in a proper situation; so, on the contrary, magnets may lose much or the whole of their power by being improperly situated; for, the same action of the earth which tends to render them magnetic in the former, will endeavour to destroy it in the latter. The same thing must be understood of the

* Gassendus, Mersennus, and Gilbert, maintain that the weight of needles is not altered by being made magnetic. Mr. Whiston says he found, by accurate experiments, that a piece of steel, weighing $4584\frac{1}{2}$ grains, lost $2\frac{1}{4}$ grains; and another, which weighed 65726 grains, lost 14 grains, by being made magnetic. With other persons, magnetism seems to have increased the weight of steel.—But it is very probable that the vicinity of iron, or of some other ferruginous body, might have had some action on the magnetic steel when it was weighed.

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situation of magnets with respect to each other. Thus, if two magnets be placed so that their contrary poles may be contiguous to each other, they will preserve one another's power; but if the north pole of one be placed near the north pole of the other, and the south near the south, then they will entirely destroy or diminish each other's magnetism; and if their original powers were very unequal, the polarity of the weaker magnet will be changed by the action of the stronger one.

In general, the same means, which facilitate the communication of magnetism, when pieces of iron, &c. are properly situated with respect to the poles of the earth, or of other magnets, will likewise facilitate the loss of magnetism, when the magnets are improperly situated; thus, a red heat destroys in a great measure, or entirely, the power of a magnet. A steel bar, strongly magnetic, will have its power much diminished by being repeatedly struck between two stones, especially if it be struck standing in a direction perpendicular

lar to the magnetic meridian. A bar of pretty hard iron, which has acquired some degree of permanent magnetism, by being made red hot, and then cooled in the direction of the magnetical line, will have that power destroyed, or much diminished, by a few smart blows on its middle.

We shall now conclude this chapter with an enumeration of those particulars which are principally necessary to be kept in view, in order to ascertain the best method of constructing artificial magnets; reserving the practical instructions for the third Part.

1. The nature of the body must be adapted to the power which is to render it magnetic; remembering, that the soft ferruginous bodies both acquire and lose magnetism easier than those which are harder.

2. The shape of the bodies is to be considered next, experience shewing that an oblong one is in general preferable to any other. In case of steel bars, they ought to be quite hard, in order to acquire the greatest possible power, provided one has mag-

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nets sufficiently strong for the purpose ; and if cylindrical, their diameters ought to be about $\frac{1}{3}$ th of their length ; or if not cylindrical, their thicknesses ought to be such as nearly to equal the weight of the cylindrical bars of the same length, and the diameter of which may be about $\frac{1}{3}$ th of their lengths.

3. Several magnets are much preferable to a single one, for the purpose of communicating magnetism ; in the application of which, it must be remembered, that the south pole of the magnet produces a north pole in the part of the ferruginous body to which it is applied, and that the north pole of the magnet produces a south pole in the part, &c.

4. If it were required to construct a strong magnet, when the operator has either no magnet at all, or a very weak one ; he must proceed gradually. It being impossible for a hard and large steel bar to receive any sensible degree of magnetism from the action of the earth, or of any other weak magnet, the operator must begin with

with giving magnetism to several small and soft steel bars, impregnating one at a time by means of the weak magnet, or, if he have no magnet, by means of one or more iron rods properly situated, which in that case are real, though weak magnets. Then, by joining in a proper manner the small steel bars already made magnetic, he may communicate a stronger power to larger and harder steel bars; which will be capable of impregnating bars still larger; and so on.

CHAPTER VIII.

Promiscuous observations.

THE directive power of a magnet is extended to a greater distance than its attractive power; for instance, if a magnet be freely suspended, another magnet, properly situated within a certain dis-

H tance

tance of the former, will turn it out of its wonted direction; yet the degree of attraction exerted by those magnets against each other, is not sensible at that distance; which may be easily tried, by fixing one of the magnets to the scale of a balance. The reason of this property is, that the directive power depends both upon the attraction of the poles of different names, and on the repulsion of those of the same name; whereas the attraction takes place only between poles of different names.—In order to render this explanation more intelligible, imagine that a magnetic needle is freely suspended, and is placed within the influence or sphere of action of a magnet. In this disposition, suppose that the north pole of the magnet attracts the south pole of the magnetic needle with a force equal to ten grains; and, as the attraction between poles of different names is nearly equal to the repulsion between poles of the same name, it follows, that the same north pole of the magnet repels the north pole of the magnetic needle with a force equal to ten grains:

grains : but those two forces both concur in altering the direction of the needle ; therefore, the endeavour of the magnet, to turn the needle's direction, is equal to 20 grains ; whereas the attraction, or the force by which the needle is drawn towards the magnet, is only equal to the difference between the two above-mentioned opposite forces, which difference arises from the pole of the magnet being nearer to one than to the other of the poles of the needle.—The same reasoning may be applied to the action between the south pole of the magnet and the suspended needle.

It has been asserted by various authors, that if a short bar of soft steel be repeatedly stroked from end to end, in any situation, by a sufficiently long iron bar, likewise kept in any situation, the steel bar will thereby acquire a considerable degree of magnetism : from which it might perhaps be inferred, that there is no necessity of deriving the origin of magnetism from the earth. But an accurate investigation of this pretended fact has shewn, that the

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steel bar will not acquire magnetism in every situation. Indeed, as the bar of iron is rendered more or less magnetic by the earth in every situation, except that which is perpendicular to the magnetical line ; in a random way of making the experiment, it is almost impossible to keep the bar so near that direction as to acquire no magnetism at all from the earth ; but if, in rubbing the steel bar, the iron one be kept in a situation nearly perpendicular to that of the magnetical line, then the steel will acquire no magnetism at all. Besides, when the iron bar is kept in any situation, the degree of magnetism which it communicates to the bar is greater or less in proportion as the direction of the bar is nearer to or farther from that of the magnetical line ; which proves, beyond a doubt, that the communicated magnetism is originally derived from the earth.

Thus far, relating to the laws of magnetism, seems sufficient to be inserted in this Part of the present work ; and though there are several other particulars necessary to be known, yet, as they either relate to

the

the practical part, or cannot be easily understood without the description of other experiments, so they will be inserted in other places, which are more adapted to their reception. I shall, therefore, conclude this Part with removing some wrong notions relating to magnetism, which have been introduced by ignorance and imposition.

The impostors, who are always ready to seize every opportunity of defrauding the rest of mankind, and the ignorant, who are always fond of mysteries, have, from time immemorial, attributed several extraordinary properties to the magnet, which are not only repugnant to reason, but are actually contradicted by all the experiments which have been made, and may be repeated by intelligent and impartial persons.

It was formerly believed, that there existed several sorts of magnets, some of which attracted gold, others attracted flesh, &c.; but even very lately it was believed, by ignorant people, that there was a white loadstone, which had the property of at-

tracting flesh : the origin of which error is, that there are several minerals of an earthy kind, mostly argillaceous, which absorb moisture very fast ; in consequence of which, if they be put upon the lips, they will adhere to it with some degree of force.

A great deal of confusion in the science of magnetism has been also occasioned by the application of the word *magnetism* to other things, which had nothing to do with it. The chymical affinity between metals, has been called the magnetism of metals, by some old authors. The vibration occasioned by the sound of musical strings or pipes, upon others which were tuned in concord to them, has been also called the magnetism of music. We hear likewise of the magnetism of astronomy, the magnetism of water, &c.

But the greatest absurdities relating to the magnet are, its pretended medicinal properties. As late as the beginning of the last century, it was pretty commonly believed, that a plaster made with powdered loadstone, when applied to wounds, would extract

extract iron, or even a knife, from the human body*.—It was said, that the chymists could extract an oil of wonderful efficacy from the magnet, besides several other preparations. Even at present it is not unusual to find people who believe, that the application of the magnet cures the tooth-ach, eases the pains of parturient women, disperses white swellings, &c.; and, on the contrary, that the wounds made with a knife, or other steel instrument, which has been previously rubbed with a magnet, are mortal.

Without detaining the reader any longer with the narration of more absurdities, I shall only observe, that authentic facts prove none of those pretended medicinal or poisonous qualities in the magnet; and, as magnetism does not affect the smell, the taste, or any other sense of the body, it is improbable, to the greatest degree, that it should have any effect upon animal

* Kircher, who was himself of the contrary opinion, relates several such stories. See his work *de arte magnetica*, lib. iii. chap. ii.

bodies. For though there are particles of iron in almost every part of an animal body, yet those particles are so subdivided, calcined, and bear so small a proportion to the other elements, that, in a natural state, the magnet has no action on them.

P A R T II.

THEORY OF MAGNETISM.

THE attraction of the magnet, and very likely most of its other principal properties, have been noticed and admired from time immemorial; but the cause of those surprising properties has eluded the most accurate researches of very able philosophers. Various theories have been framed for their explanation, and many conjectures have been derived from other powers of nature, which were in some measure analogous to magnetism; but there is a wide difference between matter of fact and the offspring of the imagination. The former is investigated and acquired with labour, and rewards the industry of the searcher; the latter often shews the weakness

weakness of human understanding, and misleads the blind follower.

Nevertheless, the framing of hypotheses in explanation of natural phenomena, has been of some use in philosophy, since they have at least promoted the experimental enquiry, either for their support or for their destruction ; the distinguishing characteristics between a false hypothesis, and a true, or very probable one, being, that by farther and farther examination, the sufficiency of the latter, in explaining the natural appearances, becomes constantly more evident, whereas the absurdity of the former is rendered more manifest. It is therefore useful, after having ascertained a number of facts or laws of nature, to attempt a theory for their explanation, especially because, when such theory, *viz.* the real cause, is once established, the application of its effects becomes more easy and general. But every enquirer into the operations of nature ought to be seriously warned against becoming too fond of any hypothesis, even when it seems to have the greatest degree of probability.

In

In conformity to those observations, the reader must not expect to find, in this Part of the present work, a particular account of all, or even of the principal hypotheses that have been published at different times by divers authors. I shall only mention, in brief, what seems to be more probable, or what may lead to a farther investigation of the subject; and must then refer those, who are desirous of examining other hypotheses, to the various books written on magnetism.

CHAPTER I.

Of the magnetism of the earth.

THE hypothesis of the earth's being a great magnet, from which the magnetism of the usual magnets, the direction of the magnetic-needle, &c. must be derived, is evinced by so many observations, that there can hardly be a philoso-

pher sceptic enough to doubt of its truth. The principal reasons which prove it, almost to a demonstration, are, first, that almost all the phenomena which may be exhibited with a usual magnet, may be also exhibited with the earth, as far as it may be tried; and, secondly, that vast masses of iron, or ferruginous substance, actually magnetic, are dug out of the earth almost in every part of it.

The phenomena of the compass, and of the dipping-needle, in different parts of the world, and the magnetism naturally acquired by soft iron when properly situated, are exactly imitated by a common magnet or a terrella; but the only phenomenon, which has not been observed with respect to the earth, and which is the principal property of the usual magnets, is the attraction of a piece of iron, or other ferruginous substance. For instance, if a piece of iron be presented to either of the poles of a common magnet, it will be attracted powerfully by it; but if it be presented to the middle of the magnet, the attraction will be found to be hardly perceptible; or at least

least incomparably weaker than at the poles; in conformity to which, it might be expected, that a piece of iron should be attracted more powerfully downwards when near the poles of the earth than when near the equator, which attraction, being combined with the attraction of gravitation, ought to be known by the difference of the weights of the same piece of iron, when weighed near the poles, and when weighed near the equator; for, if the magnetic attraction of the earth upon it be at all sensible, it ought to weigh more in the former case than in the latter. But this difference of weights has not yet been ascertained; however, if it were to be tried with all the accuracy necessary for so nice an experiment, I am inclined to think that it would be found to answer, *viz.* that the same piece of iron would be found to weigh somewhat more, in places nearer to the poles, than it does nearer to the equator; but even, in case no such difference of weights were observed, it would be improper to infer that the earth does not exert any magnetic attraction towards the iron on its surface,

surface, and that this attraction is not stronger near the poles than near the equator ; because, first, the magnetism of the earth being very weak, the difference of the attraction in different places must be likewise very small, notwithstanding the directive power is considerably strong ; for, as was explained in the preceding Part, the latter of those powers extends to a much greater distance than the former. And, secondly, it must be considered, that the equatorial diameter of the earth is longer than its polar diameter, and that the attraction of gravitation, or the weight of bodies, decreases in proportion to the squares of the distances from the centre of the earth ; in consequence of which, if we abstract the magnetic attraction, and consider only the attraction of gravitation, it will appear, that the piece of iron must weigh more when weighed near the poles than when weighed near the equator ; namely, because, when near the poles, it stands actually nearer the centre of the earth than when near the equator.

If the magnetic needle pointed always due north

THEORY OF MAGNETISM. III

north and south, or always within a certain distance of those points, it would show that the earth has two fixed magnetic poles, either coinciding with its astronomical poles, or at some distance from the same; but the continual variation of the magnetic needle shows, that those magnetic poles of the earth move with respect to the surface of the earth, and, on this account, many suppositions have been offered to the public by divers ingenious persons. It was imagined, that there was a large magnet inclosed within the body of the earth, which being not fixed to the external part, moved with respect to it, and, consequently, occasioned the variation of the needle; but in this case the variation ought to be regular, *viz.* it ought to move in all parts of the world, so as to answer to the two points of the large internal magnet; which, however, is not the case.

In order to supply the deficiency of this hypothesis, it was farther imagined, that there were four magnetic poles with-

in the earth, which were moveable with respect to each other, and that, therefore, the variation of the needle ought to be derived from all their actions conjointly; which would render the theory of the variation exceedingly intricate: but, notwithstanding this difficulty, a regularity, within certain laws and limits, ought to be still observable respecting the variation; but no such regularity has been yet proved. In short, without detaining my reader any longer on this point, it will suffice to say, that no theory yet offered has been sufficient to foretel, with certainty, the variation of the needle for any future period of time, or for any place distant from those in which observations have been frequently made.

It is now proper to give a short account of the principal variation charts that have been published, *viz.* that of Dr. Edmund Halley, which was formed upon the observations made in the beginning of the present century; and the other chart, formed by Messrs. Mountaine and Dodson, upon

upon the observations made in the course of the year 1756 *.

The method used in the construction of those charts is, to mark down with dots, on a general map of the world, all the places in which the declination of the magnetic needle has been ascertained, and then to draw lines through those points, observing to let the same line, whether crooked or straight, pass through all those points or places in which the declination of the needle is the same; thus, for instance, a line is drawn through all those places in which the declination is 10 degrees west; another line is drawn through those places where the declination is of another number of degrees, and so on; which are called *lines of declination* †. It is evident, that

* See the Phil. Trans. for the year 1757.

† Those lines which pass through the points where the north end of the needle declines to the east of the meridian of the place, are called *lines of east declination*; those which pass through the points where the north extremity of the needle declines to the west of the meridian, are called *lines of west declination*; and lastly, those lines which pass through those points where the needle coincides with the meridian, are called *lines of no declination*.

in such charts the variation of the magnetic needle, in many places, must be merely a matter of conjecture or guess; and, though there is a kind of tendency of the lines of declination towards certain principal points, yet that seeming regularity is subject to many exceptions, which render those declination charts of no great use.

In Dr. Halley's chart, the line of no declination crosses the meridian of London at about the 55th degree of south latitude, it then proceeds in an arched manner towards the west of the said meridian, and increasing its curvature as it advances up into the northern hemisphere, terminates at Charles Town on the coast of North America.

In the other of the above-mentioned charts, the line of no declination passes more westward of the meridian of London, advances with a more irregular curvature, and terminates on the coast of Florida, at about the 30th degree of north latitude.

The lines of east variation are on the concave side of the above-mentioned line,
and

and the lines of west declination are on its convex side, advancing for a considerable extent with nearly the same curvature as the line of no declination : but, as you come on this side of the tropic of Cancer, the lines of west declination, in both charts, are almost perpendicular to the meridians.

In the Indian sea, and in the sea between the island of Madagascar and the south pole, the declination lines are considerably more irregular, so as to render it impossible to convey any distinct idea of the same by writing : the reader, therefore, who is willing to examine this subject much farther, may consult the said charts themselves.

There is one thing remarkable to be observed in those charts, which is, that the declination lines do never cross each other.

In my opinion, it seems that the magnetism of the earth arises from the magnetism of all the magnetic substances therein contained, and intermixed with other bodies ; that the magnetic poles of the earth may be considered as the centres of the pola-

rities of all the particular aggregates of the magnetic substances; and that those principal poles must change place, relatively to the surface of the earth, according as the particular aggregates of magnetic substances within the earth are in some manner or other altered, so as to have their power diminished, increased, approached, or removed from the principal poles. But, as those thoughts are mostly depending on some experiments of mine, I shall defer saying any thing farther about them till after the account of those experiments; which will be found in the fourth Part.

Though no regularity has been established with respect to the variation of the needle, yet, as the various situation of the magnetic poles within the earth occasions a great variety of appearances, and as the right understanding of those varieties may be of great use to those who wish to investigate this intricate subject, the developement of which would be of vast use to mankind; I shall now subjoin the principal cases, which seem possible,

sible, relating to the position of the magnetic poles; imagining, as is most natural to suppose, that they are two, and that they lie on the surface of the earth. These cases are no more than four, *viz.**.

CASE I. If the magnetic poles of the earth had coincided with the true poles thereof, there could have been no declination or variation of the mariner's compass in any part of the world (that is, if the earth be uniformly-magnetical); for in that case the needle, in pointing to the magnetic poles, would always have pointed to the true poles also; this needle would therefore be necessarily directed along the course of the meridian, or, in other words, it would have no declination or variation either to the east or west thereof.

CASE II. If the magnetic poles were situated in the same meridian, and in opposite parallels; upon that meridian

* These four cases were drawn up by Dr. Lorimer, a gentleman of great knowledge in magnetics.

which passes through the magnetic and true poles, from the one of the magnetic poles to the other, and upon the opposite meridian all along, there could be no declination, for the reason mentioned in the former Case. Likewise, upon the equator there would be no declination ; for though if one of the magnetic poles were only to act upon the needle, in passing along the equator to the distance of 90 degrees in longitude east or west, the declination would increase, so that at 90° distance from the line of no declination it would be equal to the angle contained between the magnetic and true poles ; yet, as the other magnetic pole, in this case, is always within the same distance of the needle, it will act upon the opposite end of it with equal force, and consequently will keep it parallel to itself all round the equator. But in going from the equator north or south, the declination would increase so as to be 180° on the little arches or spaces of the meridian contained between the true and the magnetic poles, which is the greatest possible

sible declination in all cases whatsoever. It must be farther observed on this case, that the lines of no declination, including those arches of 180° , form two great circles of the globe along the meridian and the equator, crossing one another at right angles, and dividing the surface of this globe into four quarters, two in each hemisphere, the one hemisphere having west declination in the north and east declination in the south half thereof, and in the opposite hemisphere it would be just the reverse; so that each of the arches or semi-circles of no declination would have east declination on the one side of them, and west declination on the other. The small arches of 180° declination, which are between the true and magnetic poles, may be reckoned in all cases as a part of the lines of no declination; for there indeed the needle conforms itself to the meridian as well as in the other parts of the circle, though its ends are reversed. In short, as all the lines of declination do coincide and terminate in the magnetic and true poles, so these arches of 180° are

a kind of limit, making with each of those lines, as in the present case, a curve line or figure returning into itself; which figures, from 180° between the poles, to 0° declination upon the equator, do each of them include a space larger than the other, till at last they fill up the whole quarter of the surface of the globe, and conform themselves, as nearly as possible, to the shape and figure thereof.

As a variety of this case, it may be added, that the magnetic poles may be situated in the same meridian, but in parallels which are not opposite. In that case the only alteration which could happen is, that in the hemisphere in which the magnetic and true poles are nearest to each other, the figures formed by the lines of declination become smaller, and the corresponding figures in the opposite hemisphere, larger. The line of no declination, which, in this case, represents the equator, would also be proportionably nearer to those poles which are nearest to one another.

CASE III. If the magnetic poles were situated in opposite meridians, and in opposite parallels; upon those meridians which pass through the magnetic and true poles there could be no declination, for the reasons mentioned in the former Cases. But upon the equator, eastward or westward, to the distance of 90° in longitude, the declination would actually increase, so as there to be equal to the angle which measures the distance between the true and the magnetic poles; and from thence it would, in the same manner, decrease for the other 90° to the opposite meridian. The declination lines of 10° , 20° , &c. as far as the greatest declination upon the equator, in this case become arches or curves, which conform themselves, as nearly as may be, to the course and direction of the lines of no declination, and are called lines of the first order. But the lines of the greatest equatorial declination cross one another at the distance of 90° in longitude from the meridian or circle of no declination, something in form like the letter X, or like two gothic arches joined at the vertex.

vertex. They are called lines of the second order, and may very properly be considered as the boundary between the lines of the first and third order, as the lines of no declination are always boundaries between the lines of east and west declination. In this case, those lines of no declination, including the arches of 180° , form only one great circle along the meridian, dividing the surface of this globe into two hemispheres, in the one of which there is east declination, and in the other west declination.

From the greatest equatorial declination to the arches of 180° , the declination lines of the third order are curves returning into themselves, and in shape nearly resembling parabolas erected upon those arches of 180° .

As a variety of this case, it may be added, that if the magnetic poles were situated in opposite meridians, but in parallels which are not opposite, then, in that hemisphere in which the true and the magnetic poles approached nearest to one another, the figure formed by the lines of declination would

would be smaller, and in the opposite hemisphere the corresponding figures would be larger in proportion.

CASE IV. This case is a very extensive one, *viz.* when the magnetic poles are situated neither in the same nor in opposite meridians; and this seems to have been the real position of those poles ever since any observations of the declination of the magnetic-needle have been made.

In this Case, then, the lines of no declination cannot be either in the direction of a meridian or along the equator, as in the former Case, but in a kind of curves, which are variously inclined to both; and they divide the surface of the globe into two parts, but these parts are not hemispheres, as in the last Case, for they may be of a very different extent. If the magnetic poles be situated in meridians nearly opposite, the curvature of those lines will not be so great, that is, they become more like to Case III. But as the magnetic poles approach nearer to the same meridian, the curvature of the lines of no declination becomes greater, till they almost touch one another, something

thing in form like the figure of the number 8, and at last they complete the two great circles, as in Case II. The lines of the second order, which correspond to the greatest equatorial declination, if the magnetic poles be situated in meridians nearly opposite, have a declination nearly equal to the angle formed between the magnetic and true poles, as in Case III; but as the magnetic poles approach towards the same meridian, this declination decreases, till at last it entirely vanishes, as in Case II. The other declination lines in this Case are so similar to the former, that they require only to be referred to it. Lastly, it must be observed, that, whether the magnetic poles be situated in opposite parallels or not, makes as little difference in this as in the former Case.

Hitherto the magnetic poles have been considered to lie on the surface of the globe; but if we attentively consider the situation which they may more likely have, it will appear, that in all probability they are not situated near the surface of this globe, but at some depth below it; at least this

this must be the case with the south pole; for, since the water of the sea is incapable of magnetism, and the southern hemisphere, especially about the south pole, contains a vast deal more sea than land; it is plain that the south magnetic pole must be situated at least near the bottom of the sea; in consequence of which, the variation of the needle in that hemisphere must be different from what it would be if the magnetic pole were situated on the surface of the terraqueous globe. The same may be observed with respect to the situation of the north magnetic pole. Besides this, we must also consider the irregularities arising from the unequal and irregular situation of land and sea; it being natural to conceive, that large tracts of land on one side of the magnetic needle, will draw it away from the real meridian, whereas a large ocean can produce no such effect.—This, however, is subject to a great deal of variety, arising from the nature of the land, the depth of the sea, the nature of the ground at the bottom of the sea, &c. It appears, therefore, that a great many

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many causes combine to act upon the magnetic needle, occasioning it to decline from the true meridian, and that it is almost impossible to form a useful theory upon it. However, as this is a subject of vast importance to mankind, principally for the improvement of navigation, I am far from meaning to discourage its being properly examined ; but only think it necessary to put all the apparent difficulties before the eye of the resolute adventurer in this field of intricate and difficult investigation.

CHAPTER II.

Analogy between magnetism and electricity.

WHEN the knowledge of mankind, relative to electricity, comprehended only the property of amber, and of a few other bodies, which, after being rubbed, attract small bodies, this attraction was hardly distinguished from that of magnetism ;

netism; and in fact old books often describe the above-mentioned property of amber, under the appellation of the magnetism of amber. The modern scientific improvements, especially those made within this century, have shewn, that electricity and magnetism are two different powers of nature, which are quite distinct from each other; but, at the same time, it must be confessed, that there is a surprising analogy between them; and, as it is by following the similarity between two subjects, that discoveries are often made in philosophy, it seems necessary in this place to point out the particulars in which magnetism and electricity resemble each other, and likewise those in which they more essentially differ.

That power which philosophers call electricity, is of two sorts, namely, the *positive* and the *negative electricity*. It is an invariable law in electricity, that bodies possessed of the same sort of electricity repel each other, whereas those which are possessed of different electricities attract each other.

Thus

Thus, in magnetics, there is a north and a south pole; those parts of magnetic bodies which are possessed of the same polarity repel each other; but those which are possessed of different polarities attract each other.

In electricity, whenever a body in a natural state is brought within the sphere of action of an electrified body, it becomes itself electrified, and possessed of the contrary electricity, after which an attraction takes place; so that in truth there is no electric attraction but between bodies possessed of different electricities: for instance, if a piece of paper be brought sufficiently near a glass tube, electrified positively, the paper will acquire the negative electricity, and will then be attracted by the tube; but if the paper be so circumstanced as not to have it in its power to acquire that negative electricity, then no attraction will take place.

Thus a ferruginous substance, which is brought within the sphere of action of a magnet, cannot be attracted by either pole of the magnet, unless it acquires first a contrary polarity.

One sort of electricity cannot be produced by itself, but is always accompanied by the other ; thus, if a glass tube be electrified positively on its external surface, a negative electricity must exist, either on its internal surface, or on the air contiguous to the tube.

In the same manner, the two magnetic poles are always together ; nor was there a piece of ferruginous substance ever produced, which had one polarity and not the other.

The electric virtue can be retained and confined by certain bodies, like glass, amber, resins, and others, called *electrics* ; but it easily pervades other substances, called *conductors, or non-electrics*.

The magnetic virtue is retained by ferruginous substances, especially those of a hard nature, like hard steel, and the magnet : but it pervades easily, and without the least perceptible impediment, all other sorts of substances.

On the other hand, the magnetic power differs from the electric, first, in its not affecting our senses with any light, smell, taste, or noise ; whereas the electric spark, shock,

smell, and taste, are known to every person conversant in electric experiments. Secondly; magnetism attracts only iron, or those bodies which contain that metal in some state or other, whereas, the electric power attracts bodies of every sort. Thirdly; the electric virtue resides on the surface of electrified bodies; whereas the magnetic is quite internal. Lastly; a magnet loses nothing of its power by magnetizing other substances; but an electrified body loses part of its electricity by electrifying other substances. Here, however, must be remarked, that an electrified body loses part of its power, when in electrifying another body touches it, and that body acquires then the same sort of electricity; but when that other body is electrified by being only brought within the sphere of action of the former, in which case, it acquires the contrary electricity, then the former body loses nothing of its power; for instance, suppose that a body A possesses a certain quantity of positive electricity, and that another body B, in a natural state, be gradually brought near A; then the body B, when it comes within a certain distance of the electrified

electrified body A, acquires a negative electricity, which negative electricity takes away nothing of the power of the body A ; but if the two bodies come very near, so as to touch, or as that the electricity of the body A may leap from it to the other, then the body B will become electrified positively, and A loses thereby part of its power.—Indeed, if it be duly considered, this last case does not seem ever to take place with magnetism ; for bodies appear to be rendered magnetic merely by the action of their spheres of activity, or by that power which enables magnets to act at some distance from their own bodies ; and therefore we may justly say, that electrified and magnetic bodies agree in this, *viz.* that they lose nothing of their power, when other bodies are electrified or rendered magnetic in virtue of their spheres of activity.

Several other points of analogy, or of difference, between magnetism and electricity, will, perhaps, occur to those persons who examine both subjects ; but if they be attentively considered, I think they will

be found to be comprehended in those which have been enumerated above.

CHAPTER III.

Of the hypothesis of the magnetic fluid.

THE great desideratum in magnetics is, to know the cause which, in a magnet, of whatever sort it may be, produces the attraction, repulsion, and other magnetic phenomena. It is really surprising to observe, that, by the mere contact, or even by the vicinity of a magnet, a piece of steel, &c. acquires several extraordinary properties, which it afterwards retains obstinately, and that without having its weight, shape, colour, or hardness altered in any sensible degree, and without the appearance of any substance being communicated to it by the magnet, which substance is either perceived by our senses, or at all hindered by the interposition of any known body.

Human imagination, ever ready to supply the deficiency of real knowledge, has

has offered abundance of hypotheses; but their insufficiency to explain the various phenomena of magnetism, renders them mostly improbable, and often evidently absurd. Some have imagined, that the pores of ferruginous bodies are full of valves, which permit the passage of the magnetic fluid in one direction, but prevent its return backwards. Others have imagined, that there is a perpetual circulation of a certain fluid from one pole to the other of every magnet; and of course, that on the earth, which is a great magnet, there is likewise a perpetual circulation of this magnetic fluid from the regions adjacent to one pole to those adjacent to the other.

Without detaining my reader with the particular account, and confutation of those and other hypotheses, I shall only take notice of the hypothesis proposed by the ingenious Aepinus, which, though labouring under several objections, seems however to be the most plausible*.

* *Tentamen theoriæ electricitatis et magnetismi*, auctore F. V. T. Aepino, chap. i. § iii.

From the analogy of the established or more common hypothesis of electricity, which goes under the name of Dr. Franklin's, Mr. Aepinus is led to imagine, that there exists a fluid productive of all the magnetic phenomena, and consequently to be called *the magnetic fluid*; that this fluid is so very subtle as to penetrate the pores of all bodies; and that it is of an elastic nature, *viz.* that its particles are repulsive of each other.

He farther supposes, that there is a mutual attraction between the magnetic fluid and iron, or other ferruginous bodies; but that all other substances have no action with this fluid; they neither attracting nor repelling each other.

He then observes, that there is a great deal of resemblance between ferruginous bodies and electrics, or non-conductors of electricity; for the magnetic fluid passes with difficulty through the pores of the former, as well as the electric fluid passes with difficulty through the pores of the latter. However, there is not a body that has any action on the magnetic fluid, and is,

is, at the same time, analogous to non-electrics; for instance, there is no body, the particles of which attract the magnetic fluid: and yet this fluid can pervade its pores without any obstruction. In iron, indeed, a kind of gradation of this sort seems to take place; for the softer the iron is, the more freely does the magnetic fluid pervade its pores, and, on the contrary, the harder it is, the greater opposition it offers to the free passage of that fluid; so that the iron, when soft, seems to be more analogous to non-electrics than when hard.

According to this hypothesis, iron, and all ferruginous substances, contain a quantity of magnetic fluid, which is equably dispersed through their substance, when those bodies are not magnetic; in which state they shew no attraction nor repulsion against each other, because the repulsion between the particles of the magnetic fluid is balanced by the attraction between the matter of those bodies and the said fluid, in which case those bodies are said to be in a natural state: but when, in a ferruginous

body, the quantity of magnetic fluid belonging to it is driven to one end, then the body becomes magnetic, one extremity of it being now overcharged with magnetic fluid, and the other extremity, undercharged. Bodies thus constituted, *viz.* rendered magnetic, exert a repulsion between their overcharged extremities, in virtue of the repulsion between the particles of that excess of magnetic fluid; which is more than overbalanced by the attraction of their matter. There is an attraction exerted between the overcharged extremity of one magnetic body, and the undercharged extremity of the other, on account of the attraction between that fluid and the matter of the body; but to explain the repulsion, which takes place between their undercharged extremities, we must either imagine that the matter of ferruginous bodies, when deprived of its magnetic fluid, must be repulsive of its own particles, or that the undercharged extremities appear to repel each other only because either of them attracts the opposite overcharged extremities;

mities ; both which suppositions are embarrassed with difficulties.

A ferruginous body, therefore, is rendered magnetic by having the equable diffusion of magnetic fluid throughout its substance disturbed, so as to have an overplus of it in one or more parts, and a deficiency of it in one or more other parts ; and it remains magnetic as long as its impermeability prevents the restoration of the balance between the overcharged and undercharged parts. Moreover, the piece of iron is rendered magnetic by the vicinity of a magnet, because, when the overcharged part or pole of the magnet is presented to it, the overplus of magnetic fluid in that pole, repels the magnetic fluid away from the nearest extremity of the iron, which therefore becomes undercharged, or possessed of the contrary polarity, to the most remote part of the iron ; which consequently becomes overcharged, or possessed of the same polarity as the presented pole of the magnet. When the piece of iron is rendered magnetic by presenting

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ing to it the undercharged extremity or pole of the magnet, then the part of the iron which is nearest to it, becomes overcharged, &c. because that part of the magnet, being deprived of its magnetic fluid, attracts the magnetic fluid of the iron to that extremity of the iron which lies nearest to itself.

In consequence of which it appears, that, in order to give magnetism to a body, as a piece of steel, the strength of the magnet employed must be such as to overcome the resistance, which the substance of the steel makes against the free passage of the magnetic fluid ; hence, a piece of soft steel is rendered magnetic more easily than a hard one ; hence, a stronger magnet will render magnetic such ferruginous bodies as other smaller magnets have no power upon.

The action of two magnets upon each other is likewise easily explained by this hypothesis. When two equal magnets oppose their contrary poles to each other, they thereby preserve and strengthen their power ; but when the homologous poles of

two magnets are placed near, then, if the strength and quality of those magnets be equal, they will only diminish each other's magnetic power ; but if they be unequal in power or other quality, as the hardness, shape, &c. then the weakest will have its power diminished, destroyed, or changed, in proportion to its softness, weakness of magnetism, and other circumstances, which will easily occur to the intelligent reader.

P A R T III.

PRACTICAL MAGNETISM.

THE object of this Part of the present work is, to describe those experiments which are necessary to prove the laws of magnetism mentioned in the first Part ; and also, to describe those instruments which are necessary for the uses to which magnetism is subservient. In this description, both of experiments and of instruments, I shall principally insist upon those particulars, which, being of a general nature, may serve as fixt points to guide the ingenious experimenter in the contrivance of more perfect instruments, and in the performance of the necessary experiments by the most easy means, it being

being very well known, that, to be obliged to procure a particular instrument for almost every experiment, which is mostly the case with beginners, when complicated and formal apparatuses are described, considerably retards the propagation of useful knowledge.

CHAPTER I.

Description of the magnetical instruments.

IF we collect under one point of view the magnetic properties, it will be found that they may be comprehended under two general classes, namely, the action of the magnet upon unmagnetic ferruginous bodies, and the action of one magnet upon another. The first consists only in communicating the magnetic power; the second comprehends the attraction and repulsion, a consequence of which is the directive property, *viz.* the compass and dipping needle. Therefore, the principal instruments

instruments in magnetics are, a few magnets or magnetic bars, a magnetic needle for the magnet's horizontal direction, and the dipping needle, to shew the inclination.

If one do not want to be very nice and particular, a common horse-shoe artificial magnet, which costs very little, and a few sewing-needles, will shew several experiments ; but persons who wish to be more exact, and to make improvements in the subject, ought to be provided with a good set of artificial magnets, which usually consists of six bars, a few small magnetic needles, a pretty large needle in a proper box with a graduated circle, and a dipping needle; to which may be added, some pieces of steel wire, two or three bars of soft iron, and a few other things of no great expence, but very useful for various experiments.

In this chapter I shall describe only the three principal instruments, *viz.* the bars, the needles, and dipping needle, the rest being mentioned occasionally in the description of the experiments.

The

The magnetic bars are generally six in number, and they ought to be made of the best steel, and left quite hard; but, however, there is not a characteristic yet known, by which the steel, capable of acquiring the greatest magnetic power, may be distinguished. It will be proper, therefore, to try the steel previously to using it for the construction of the bars. For which purpose, take a piece of it, about three inches long, and about a quarter of an inch in thickness (no matter whether round or square), make it red hot, and in that state plunge it in cold water, which hardens it so that a file will not touch it. This done, apply two powerful magnetic bars to its extremities; keep them in that situation for about a minute, taking care to let the north pole of one of the magnetic bars touch one extremity of the piece of steel, and the south pole of the other bar touch the opposite extremity of the steel: then try whether the piece of steel will hold suspended a key or other piece of iron that may be at hand. Thus, by trying several pieces

pieces of steel of different sorts, and by treating them all alike, you will easily perceive which is capable of lifting the greatest weight of iron, and, consequently, that sort of steel is the fittest for the construction of the bars.

The dimensions of those bars ought to have a certain proportion, otherwise they will not be capable of a very great power. The most advantageous shape is when the length is about ten times the breadth, and about twenty times the thickness; so that if they be five inches long, which is the most usual length, they ought to be about half an inch broad, and about a quarter of an inch in diameter.—The cylindrical bars are not very conveniently managed.

Some persons have described particular methods of hardening such bars, *viz.* by plunging them, when red hot, in different liquors. It has been confidently asserted, that to put them, when red-hot, in a mixture of scraped horn and common salt is very advantageous; but, upon the whole, simple cold water seems to be equal to any other substance.

It is immaterial whether those bars be polished or not; but it will be better to polish them; in that state being less apt to contract rust. One extremity of each bar is generally marked with a line all round, in order to distinguish one pole from the other, and the marked end is usually made the north pole.

To each set of bars there always belong two pieces of soft iron, called *supports*, each of which is equal to the size of half one of the bars, so that, when placed contiguous to one another in one direction, they may be equal to one of the bars. These pieces of iron are useful when some other ferruginous bodies are to be rendered magnetic, or when the same set of bars is to be strengthened in power.

When the magnetic bars are kept together, they must be placed alternately with the marked end of one contiguous to the unmarked end of the next; as shewn in fig. 4.—The method of rendering those bars magnetic will be found in a subsequent chapter.

The construction of the compass or mag-

netic needle has undergone a great variety, and almost every construction has some peculiar advantages. The simplest magnetic needle is a common sewing-needle made magnetic, and either suspended by means of a thread tied to its middle, or by laying it gently on the surface of water kept in a vessel; for if the needle be small, it will swim upon the surface of the water, notwithstanding its specific gravity is greater than that of water; there being a kind of repulsion between water and steel when clean; or perhaps the air may contribute to it. If any part of the needle happens to get a little below the surface of the water, then the needle goes immediately to the bottom. The inconvenience attending the first of the above-mentioned suspensions, is the stiffness of the thread, even of the finest sort, which prevents the free motion of the needle. The principal inconveniences attending the second are, the needle's generally going towards the sides of the vessel, and its going to the bottom on the least agitation; which however may be prevented by a piece of cork.

The

The more general, and by far the best sort of suspension for magnetic needles, is to let them rest horizontally with their middles upon sharp-pointed wires set up perpendicularly in a box or other support. The needle for this purpose must have a conical cavity in its middle, the apex of which may be above the centre of the needle ; so that when the needle is laid upon the wire, the point of which must be in the apex of the conical cavity, its centre of gravity may be below that point of suspension ; otherwise the needle would fall off very easily.

In order to answer this purpose, the needles are generally pierced quite through with a largish hole, a piece of hammered brass is then rivetted into this hole, and the conical cavity is made into the brass, so that the apex of it may stand very little above the upper surface of the needle, as at A, fig. 5 of plate I. In this construction, the point of the wire B, the very top of which is often made of hard steel, whilst the lower part is of brass, bears against the brass, and, notwithstanding that the

brass be hardened, yet by continual rubbing a small indenture, or irregular hole, &c. is often made therein, which occasions a considerable obstruction to the free motion of the needle ; to obviate which, in the best needles a piece of agate is set in the upper part of the brass, and the apex of the conical cavity is made in that hard stone, which renders the motion of the needle very free and easy. The needles thus constructed, are said to be furnished with an agate cap, and the best compasses made for the sea have this sort of cap *. Fig. 6. of plate I. shews a section of this agate cap in the brass, &c.

As a very little irregularity in the shape of a piece of steel is often productive of

* The compasses for the sea-service formerly, and some even at present, are made in the following improper manner :—the brass cap is fastened to the middle of a circular card, upon which the various points of the horizon, as the east, west, &c. are marked ; and on the under part two pieces of magnetic steel are stuck fast to it, so as to lie parallel, and to stand about half an inch distant from one another, the pin upon which the whole is suspended passing between them.

more

more than two magnetic poles, or an improper situation of the two poles, which must be always avoided; some persons, having objection to the perforation made through the needles, have thought of other suspensions, in which the perforation might be avoided; the best of which proposals is shewn in fig. 7. of plate I. where the magnetic needle A B is fastened to a piece of brass C E D, properly bent: in the middle of it, *viz.* at g, there is a small conical cavity, where an agate cap may likewise be applied. In order to suspend this needle, a bar F H, fig. 8. is made fast to the box K L, in the middle of which bar is a pointed pin I, upon which the cavity of the piece of brass that is fastened to the needle, rests; the needle A B moving below the cross-bar F H, and this cross-bar passing between the needle and the piece of brass that is fastened to it, *viz.* through g of fig. 7.—It is evident, that the needle, in this construction, cannot turn quite round; consequently, this sort of suspension is not fit for the use of vessels at sea.

The Chinese method of suspending the magnetic needle is exceedingly ingenious. The figures 9 and 10 of plate I. represent this needle very nearly of its real size, and in two points of view, *viz.* in the former the eye of the observer is in the direction of the needle; but in the latter, the eye views the needle sideway *. I is a brass cap, very thin and light, and towards the edge of it there are two holes, opposite to each other. B B is a very slender slip of brass, the upper part of which at A is shaped like a ring, through which the needle C D passes. The extremities of this slip of brass pass through the holes in the edge of the cap I, and are fastened to it by being turned over its edge. The magnetic needle C D, consists of a cylindrical steel wire, about an inch long, and not above a fortieth of an inch in diameter; and, in order to distinguish its north extremity, half of it is painted red, and the other

* These drawings were made from some Chinese compasses, brought from China by Dr. James Lind, a physician at Windsor. The needles in them are very nearly all of a size, *viz.* about an inch long.

half is black. All this is supported by the pin E, which is fastened to the bottom of the box, and upon which it moves very nimbly. In this construction, notwithstanding the needle is above the centre of suspension, yet the centre of gravity of all the three pieces that are connected together, is below the point of suspension, otherwise it could not be supported. To prevent the needle falling off, when the compass, by being carried about, is turned top-side down, there is fastened to the box a plate of very thin brass, a section of which is shewn by F G; it has a hole through the middle, which, being smaller than the diameter of the aperture of the brass cap, prevents its receding too much from the point of the wire E, and also prevents its falling sideway.

From repeated experiments, it appears, that the perforation through the magnetic needle is of no detriment, or at least not sufficient to occasion any multiplicity of poles, or to prevent the needle's due direction. Its external shape is to be more minded, the irregularities of it being by far more detrimental. The little swelling

generally made about its middle, in order to give it strength just where the perforation otherwise weakens it, does no damage, provided it be as represented in fig. 11. of plate I. and not made with points, edges, or other irregularities, for the sake of ornament. The magnetic needles, made for the best compasses used at sea, are considerably broad, and a slender brass ring is fastened to their extremities, upon which the card or paper, with the points of the horizon marked upon it, is stretched. But the great objection against broad needles is, that the two poles are frequently not in its axis. It would be therefore more proper to make them rather thick than broad; because, if in this case their poles happen to be not in its axis, but one be at D, fig. 12. plate I. whilst the other is at A, they cannot affect the direction of the needle, being, if not in its axis, at least in the same plane with it. The most eligible shape, therefore, seems to be that shewn by the figures 11 and 12, which exhibit two views of the same magnetic needle.

The length of the needles commonly used for the sea, is between four and six inches;

inches; but those which are to be used for observing the daily variation, called *variation needles*, are made longer, some of them having been made of more than two feet in length, in order to render their deviation from the meridian more sensible. However, in the present improved state of constructing philosophical instruments, if the work be properly done, a needle of about eight inches length will shew the variation within much less than half a minute.

Having thus far described the different sorts of suspensions, I shall now enumerate the particulars which must be had in view in the construction of magnetic needles; and shall then proceed to describe the principal sorts of magnetic compasses.

The magnetic needles ought to be made of that sort of steel which is the most susceptible of magnetism; and they ought to be quite hard, to retain the magnetic power longer *.

* The more common needles are improperly brought down to a blue temper; for though in that state they acquire the magnetism much easier, yet they, for the same reason, lose it much easier.

The shape ought to be as simple as possible, or free from projections and other irregularities, made by way of ornaments. In short, they ought to be constructed so as to have only two magnetic poles, and those in that same plane which passes through the centre of suspension *.

They should also be made as light as possible, in order to diminish the friction on the point of suspension; which, even when the needles are furnished with agate caps, occasions some obstruction against their motion.

The agate caps must also be made properly, *viz.* their cavity ought to be perfectly conical; which, after having examined several of them, I can assert to be seldom the case; and indeed it is very difficult to

* The hardening of a piece of steel in general, by the usual method of plunging it, when red-hot, in cold water, frequently alters the shape of it by bending it, especially when the piece of steel is of an oblong form; for which reason, in forming the magnetic needles, they ought to be left by the file somewhat larger than necessary; because, after the hardening, they may be brought to the proper size and shape by grinding on a Turkey-stone.

shape them properly, on account of the hardness of the stone.

The magnetic needles, though perfectly balanced before the magnetism is communicated to them, will afterwards incline one of their extremities, on account of the dipping property of every magnet; and, in order to make them stand horizontally, the other extremity is loaded with a little weight, or the preponderating extremity must be made lighter by grinding; the latter of which is a very improper way, because, by altering the inclination, which happens especially when the needle is removed from place to place, its horizontal position is soon destroyed, in which case it will be necessary to grind one end off again.

For this reason it is also improper to apply a fixed weight to one end of the needle, which is sometimes done by piercing a hole through the steel, and putting a piece of brass wire in it, so as to project a little on either side of the needle. The best way, therefore, of adding this weight, is to put a sliding piece of brass on the preponderating

derating extremity of the needle; for, by sliding this piece of brass nearer to or farther from the centre of the needle, the weight of that extremity is easily altered when required.

The principal sorts of magnetic compasses are four, *viz.* the magnetic needle, simply suspended in a box; the mariner's compass, or that used at sea; the azimuth compass, or that which is used principally at sea in order to find the declination of the needle at any place*; and the variation compass, which, being fixed in a convenient place on land, serves to shew the daily variation.

The first of those species requires no further description, than what may be derived from the preceding pages.

The second, or mariner's compass, consists of three parts, *viz.* the box, the card or fly, and the needle; see fig. 13. of plate I.

* This is called the *azimuth compass*, because it serves to find the variation by observing the azimuth of a celestial object; the azimuth being an arch of the horizon, contained between the north or south and the point where a plane, which passes through the zenith and the celestial object, cuts the horizon.

The box, which contains the card and needle, is made of a circular form, and either of wood or brass. It is suspended within a square wooden box, by means of two concentric circles, called *jimbols*, so fixed by cross centres to the two boxes, that the inner one, or compass box, shall retain an horizontal position in all motions of the ship, whilst the outer or square box is fast with respect to the vessel *. The compass box is covered with a pane of glass, in order that the motion of the card may not be disturbed by the wind. Respecting the construction of the needle, enough has been said in the preceding pages ; there remains only to describe the card or fly. The outer edge of this card is divided into 360 degrees ; within the circle of which divisions it is divided again into 32 equal parts or arches, called the *points of the compass*, or *rhumbs* ; which rhumbs are subdivided into quarters.

* Sometimes the jimbols consist of one circle, the axes of which are supported by the square box, whilst the axes of the compass box are just across the former.

The names of those rhumbs, beginning from the north point, and going all round, are the following: the letters standing N. for north; E. for east; S. for south; and W. for west.

N.	S.
N. by E.	S. by W.
N. N. E.	S. S. W.
N. E. by N.	S. W. by S.
N. E.	S. W.
N. E. by E.	S. W. by W.
E. N. E.	W. S. W.
E. by N.	W. by S.
E.	W.
E by S.	W. by N.
E. S. E.	W. N. W.
S. E. by E.	N. W. by W.
S. E.	N. W.
S. E. by S.	N. W. by N.
S. S. E.	N. N. W.
S. by E.	N. by W.

T A B L E,

Shewing the angles which every rhumb, and every quarter of a rhumb, makes with the meridian.

North.	North.	South.	South.	Rhumbs.	Deg.	Min.
				0 $\frac{1}{4}$	2.	49.
				0 $\frac{1}{2}$	5.	37 $\frac{1}{2}$
				0 $\frac{3}{4}$	8.	26.
N. by E.	N. by W.	S. by E.	S. by W.	1 0	11.	15.
				1 $\frac{1}{4}$	14.	04.
				1 $\frac{1}{2}$	16.	52 $\frac{1}{2}$
				1 $\frac{3}{4}$	19.	41.
N. N. E.	N. N. W.	S. S. E.	S. S. W.	2 0	22.	30.
				2 $\frac{1}{4}$	25.	19.
				2 $\frac{1}{2}$	28.	07 $\frac{1}{2}$
				2 $\frac{3}{4}$	30.	56.
N.E. by N.	N.W. by N.	SE. by S.	S. W. by S.	3 0	33.	45.
				3 $\frac{1}{4}$	36.	34.
				3 $\frac{1}{2}$	39.	22 $\frac{1}{2}$
				3 $\frac{3}{4}$	42.	11.
N. E.	N. W.	S. E.	S. W.	4 0	45.	00.
				4 $\frac{1}{4}$	47.	49.
				4 $\frac{1}{2}$	50.	37 $\frac{1}{2}$
				4 $\frac{3}{4}$	53.	26.
N.E. by E.	N.W. by W.	S.E. by E.	S. W. by W.	5 0	56.	15.
				5 $\frac{1}{4}$	59.	04.
				5 $\frac{1}{2}$	61.	52 $\frac{1}{2}$
				5 $\frac{3}{4}$	64.	41.
E. N. E.	W. N. W.	E. S. E.	W. S. W.	6 0	67.	30.
				6 $\frac{1}{4}$	70.	19.
				6 $\frac{1}{2}$	73.	07 $\frac{1}{2}$
				6 $\frac{3}{4}$	75.	56.
E. by N.	W. by N.	E. by S.	W. by S.	7 0	78.	45.
				7 $\frac{1}{4}$	81.	34.
				7 $\frac{1}{2}$	84.	22 $\frac{1}{2}$
				7 $\frac{3}{4}$	87.	11.
East.	West.	East.	West.	8 0	90.	00.

Notwithstanding

Notwithstanding the contrivance of the jimbols, the irregular motion of the compass in a rough sea is, as yet, a considerable imperfection attending the use of it in vessels. This inconvenience has been attempted to be remedied by various means, some of which are absolutely wrong, whilst others have very little effect. The least skilled sort of seamen don't like to have the needle of their compass too powerfully magnetic, because, they say, then the needle is not steady. The fact is, that when the needle is not very strongly magnetic, it follows the irregularity of the ship's motion more easily, which renders it apparently more steady; but it must be considered, that the very same cause which makes it follow the irregular motion of the ship more easily, prevents, in an equal proportion, its placing itself in the magnetic meridian; consequently, this sort of remedy is a very improper one. With the same degree of impropriety, the correction of this obstruction has been often attempted, by increasing the friction between the cap of

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the needle and the pointed wire upon which it stands suspended.

Sometimes they have stuck a few pieces of paper, like wings, on the under side of the card, which, by making a resistance against the air in the box, prevented the vibrations of the needle. For this purpose, it has also been proposed to let the needle move in oil or some other liquor, keeping it still suspended upon the pin as usual, in order to let it move concentric with the box; the oil serving only to check its vibrations.

Lastly; it has been practised to suspend the box, which contains the needle, upon a pointed wire instead of the jimbols. For which purpose, the bottom of the box has been made conical, like the bottoms of common wine bottles; the apex of which cone rested upon the pointed wire, and the convex side of the said apex, or that part of it which came within the box, supported the needle: but, upon enquiry, I am told, that at sea none of those contrivances answer better than the compass supported

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in jimbols, and constructed with the precautions mentioned above.

The azimuth compass is nothing more than the forementioned compass; to which two sights are adapted, through which the sun is to be seen, in order to find its azimuth, and from thence ascertain the declination of the magnetic needle, in the manner hereafter to be shewn. This sort of compass is represented by fig. 14. The particulars in which it differs from the usual compass are the following: *viz.* the sights F, G, in one of which G there is an oblong aperture with a perpendicular thread or wire through it; and in the other sight F there is a narrow slit, likewise perpendicular; the thread or wire H I, stretched from one edge of the box to the other; and lastly, the ring A B of the jimbols rests with its pivots on the semicircle C D, the foot E of which turns in a socket, so that, whilst the box K L M is kept steady, the compass may be turned round, in order to place the sights F G in the direction of the sun. There are on the

inside

inside of the box two lines, which fall perpendicularly along the sides of the box, just from the points where the thread H I touches the edge of the box. These lines serve to shew how many degrees the north or south pole of the needle is distant from the azimuth of the sun; for which reason, the middle of the aperture of the sights F and G, the thread H I, and the said lines, must be exactly in the same vertical plane. The use of the thread, which is often omitted in instruments of this sort, is likewise to shew the degrees between the magnetic meridian and the azimuth, when the eye of the observer stands perpendicularly over it. On the side of the box of this sort of compasses, there is generally a nut or stop, which, when pushed, bears against the card and stops it; which is done in order to read more conveniently the degree of the card which coincides with one of the perpendicular lines on the inside of the box.

The variation compass, being intended to shew the daily variation of the mag-

netic needle on land, is generally made longer than those used at sea; and, as it is not necessary to turn it round, the box, instead of being circular, is oblong, so that, when the box is kept steady, the needle can move itself for the space of about 40 or 50 degrees. The divided arches are either within the box, or upon an horizontal frame out of the box ; and then the compass is fastened on the index, which moves round the centre of the divided arch or arches, and on the edge of which there is a nonius, necessary to shew the parts of the degrees. In this last construction, the index, which, as has been just mentioned, carries the compass, must be moved so as to let its fiducial line coincide with the line which passes through the poles and centre of suspension of the needle: then the extremity of the index will point out the variation, on the divided arch, in degrees and minutes. But when the divided arches are within the box, then the variation is known by only observing the divisions, which coincide with the axis of the needle.

In both constructions, it is evident, that the beginning of the divisions of the divided arch or arches must be placed exactly in the meridian of the place, or its deviation from the meridian must be accurately known, in order that, in reading the degrees of magnetic variation, a proper allowance may be made.

Those compasses are fixed in the plane of the meridian, by looking at a meridian mark made at some distance, through a telescope which is generally affixed to them; or by situating them on a meridian line drawn in the place where they are to be fixed. But for the method of finding the true meridian of any place, the reader must be referred to astronomical books, it being an object foreign from the subject of this work.

After what has been said in the preceding pages, it is almost superfluous to observe, that in the construction as well as in the situation of the compasses, iron must be kept at a distance as much as possible; making the parts of those instruments mostly of wood, or, where wood cannot

be properly employed, on account of the divisions, strength of the parts, &c. to make use of such brass, as, upon examination, is found not to affect the magnetic needle.

The dipping needle, though of late vastly improved, is still far from having attained to any perfection. The general way of constructing it is, to pass an axis quite through the needle; to let the extremities of this axis, like the beam of a pair of scales, rest upon two supports, so that the needle may move itself vertically round that axis; hence, when situated in the magnetic meridian, it will place itself in the magnetic line, and the degrees of its inclination are shewn upon a divided circle, in the centre of which the needle is suspended.—Fig. 15. is a representation of this instrument; A B being the needle, the axis of which F E rests upon the middle of the two lateral bars C D, C D, which are made fast to the divided circle ~~E~~^{IK}F. This machine is generally placed upon a stand G; but when it is to be used at sea, is suspended by a ring

a ring H to a proper frame, so as to hang perpendicularly. When the instrument is furnished with a stand, a spirit level is generally annexed to it, and the stand has three screws, by which the instrument is properly situated, *viz.* so as to let the centre of motion of the needle, and the mark of 90° on the lower part of the divided circle, be exactly in the same line, perpendicular to the horizon.

The greatest imperfections of this instrument are, the balancing of the needle, and the difficulty of knowing whether the needle, after being made magnetic, is balanced or not; for, though it may have been perfectly balanced before, (which is ascertained by its remaining in whatever situation it may be left) yet afterwards, by the adhesion of moisture or other extraneous matter, it may easily lose its balance, which cannot be known with certainty after being made magnetic.

The method which seems the fittest to avoid the error arising from the want of balance, is, first to observe the dip of the needle, then to reverse its magnetism, by the

application of magnets, so that the end of it which before was elevated above the horizon may now be below it ; and lastly, to observe its dip again ; for a mean of the two observations will be pretty near the truth, though the needle may not be perfectly balanced. But of this more in a subsequent chapter.

I shall now add the description of an universal magnetic needle ; *viz.* a magnetic needle which shews at the same time the horizontal and vertical direction of the magnet, or, more properly speaking, places itself in the magnetical line ; whereas the dipping needle, described before, must be placed in the magnetic meridian. This universal needle was contrived by Dr. Lorimer, and a description thereof published in the first part of the 65th vol. of the Phil. Trans. ; from whence it is transcribed.

“ Description of a new dipping needle, by Dr. J. Lorimer, in a letter to Sir John Pringle, Bart. P. R. S.

“ Whenever any one meets with a terrella, or spherical loadstone, the first

thing he does is to find out its poles; and, having once discovered them, he knows immediately how any small bit of needle will be affected, if it is placed upon any part of the surface of that *terrella*. The poles are most readily discovered by trying where the filings of iron, or a small bit of needle, will stand erect upon the *terrella*; and this is generally found to be upon two points which are diametrically opposite to one another. But the magnetic poles of the earth seem to be placed obliquely to one another (see the Berlin Memoirs, 1757); though where they are actually situated is hitherto unknown; whether they are upon land or water; or, in either case, whether we can come nigh to them. Yet be these things as they may, it appears evident to me, that accurate observations, made as near to those magnetic poles as possible, with a good dipping needle, is the surest way to complete the magnetic theory of this globe, analogous to the method we pursue in examining the *terrella*. But, as all the dipping needles which I have seen, appeared to me to be

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very ill calculated, for the sea service at least, I contrived one upon a different plan, in 1764, and had it executed before I left England, by Mr. Sisson. I have called it an *universal magnetic needle*, or *observation compass*; because I can by it take the dip and amplitude, and even the azimuth, with only one assistant to take the altitude for me. The needle is of the same shape and size nearly as those used now for the compasses of the royal navy, and plays vertically upon its own axis, which has two conical points, slightly supported in two corresponding sockets, which are inserted into the opposite sides of a small upright brass parallelogram, about one inch and a half broad, and six inches high. Into this parallelogram is fixed, at right angles, a slender brass circle, about six inches diameter, silvered and graduated to every half degree, upon which the needle shews the dip, by a *vernier* if you choose; and this, for the sake of distinction, I shall call the circle of magnetic inclination. This brass parallelogram, and consequently the circle of inclination,

inclination, also turns horizontally upon two other pivots, the one above, and the other below, with corresponding sockets in the parallelogram. These pivots are fixed in a vertical brass circle, of the breadth and thickness of two tenths of an inch, and of such a diameter, as to allow the circle of inclination and the parallelogram to move freely round within it. This second circle I shall call the *general meridian*. It is not graduated, but has a small brass weight fixed to the lower part of it, to keep it upright ; and the circle itself is screwed, at right angles, into another circle, of equal internal diameter, of the same thickness, and twice the breadth, which is silvered, and graduated on the upper side to every half degree. It represents the horizon as it swings freely upon jimbols, and is always nearly parallel to it. The whole is contained in a neat mahogany box, of an octagon figure, with a glass plate at top, and one on each side, for about two thirds down. That part of the frame which contains the glass lifts off occasionally. The whole box

turns

turns round upon a strong brass centre, fixed in a double plate of mahogany, glued together cross ways, to prevent its warping or splitting; and this again is supported by three brass feet, such as are used for cases of table knives; frosted that they may not easily slip, if the vessel should have any considerable motion. It has another square deal box to lock it up in, to preserve the glass, &c. when it is not wanted for use.

"The use of this instrument is very plain, as the inclination or dip is at any time apparent from inspection only; and also the variation, if the frame is turned round till the great vertical circle lies exactly in the plane of the true meridian: for, the circle of inclination being always in the needle's vertical plane, the edge of it will evidently point out upon the horizon the variation east or west. But at sea, when there is not too much motion, you turn the frame round till the vertical circle is in the plane of the sun's rays; that is, till the shadow of the one side of it just covers the other, and the edge of the

circle

circle of inclination will then give the magnetic amplitude, if the sun is rising or setting; but the azimuth at all other times of the day; and, the true amplitude or azimuth being found in the usual way, the difference is the variation. If the motion is considerable, observe the extremes of the vibration, and take the mean for your magnetic amplitude or azimuth. When the sun does not shine so bright as to give a shadow, you can set the brass circle in a line with his body, if he is at all visible, by your eye. The principal advantage at first aimed at in this compass was, to contrive a dipping needle, which should be sufficient for making observations at sea; as those needles, to be of use, must be placed, by some means or other, in such a manner, as that all their vibrations shall be made in the true magnetic meridian, north and south, otherwise they are good for nothing. For if one of them is placed at right angles, across the magnetic line, it will stand perpendicularly up and down, in any part of the world; the least dip, therefore, is alway

always in this magnetic line. But the only method of setting a dipping needle at sea has hitherto been to place it in a line with the common compass needle; and this must be very inaccurate, if they are at any considerable distance one from the other; or if they were near, the two needles would influence one another, and neither of them could be true: nay, supposing them for once to be properly placed in this line, the least motion of the ship throws them out again. But this instrument has a constant power in itself, not only of setting itself in the proper position, but also of keeping itself so; or of restoring itself to the same situation, if at any time it has lost it; and it is curious to see how, by its double motion, it counteracts, as it were, the rolling motion of the vessel. I have only one thing farther to observe, that, as it is impossible for human hands to make any instrument mathematically true, so, when we have two graduations to look to, as in the present case, one on the north, and the other on the south end of the needle, we ought to attend

attend to both, and take the medium for the true dip or variation, pretty nearly. But in this compass there is another method of examining the observations. Take a good artificial magnet, and on the outside of the compass box point one end of it towards the needle, and by moving your magnet, you may thus guide the north-end of the needle round ^{to} the south, or *vice versa*, without opening your compass box. The magnet being then laid aside, the needle will come to its true position, after a few vibrations: but, as both the needle and the circle of inclination are now reversed *, it will not point exactly to the same division as before; yet a mean of the two will be the truth, as nearly, I believe, as it is possible for any instrument to give it.

"Query 1st. May not a part of this small difference be attributed to the direc-

* Dr. Lorimer means, that the magnet should be applied in such manner as to turn the parallelogram and circle of inclination half way round horizontally, so that that end of the axis of the needle, which before pointed to the west, shall now point to the east.

tion of the magnetic influence (whatever that be) in the steel bar? and, if such an experiment could be tried upon the present azimuth compasses, is it not probable, that the variation in them would be at least as sensible?—Query 2d. May not this be the cause that two of the best of them will differ a small matter from one another?—Query 3d. Would the ends of the needle being made angular, instead of the square form, be, in some measure, a remedy for this small variation?

“ I am, &c.”

The great objection, which seems to offer itself against the above-described instrument, is the friction, which, especially at the pivots of the circle of inclination, may obstruct the free motion of the needle.—It certainly requires a most exquisite workmanship; and the sockets wherein the pivots move ought to be made of agate.

CHAPTER II.

Experiments necessary to ascertain the presence and quality of magnetism.

THE object of the experiments of this Chapter is to shew the methods of finding out whether or no a body is attractible by the magnet, whether it possesses any magnetism or not, and, in case it does, to find out its poles.

EXPERIMENT I.

To ascertain whether a body has any attraction towards the magnet or not.

The various degrees of attraction between a magnet and ferruginous bodies, require different methods, in order to be rendered manifest.

If the given body contain an evident quantity of iron, the operator needs only bring an artificial or real magnet in contact with it, and he will soon perceive that there requires a certain force to separate

parate them again ; the quantity of which force shews the degree of attraction between the given body and the magnet : thus, when two ounces weight are required to separate them, the attraction is as strong again as when one ounce only is sufficient. In this examination, care must be had to let the magnet and body examined always present similar surfaces to each other, and to come quite into contact ; otherwise, in examining different bodies, it will be impossible to compare their various degrees of attraction towards the same magnet.

If the given body be not sensibly attracted by the magnet, when tried in the above-mentioned way ; then it must be put to swim upon some water kept in an earthen or wooden vessel, by means of a piece of cork or wood ; for if in that situation the magnet be brought sideway of it, the attraction will be soon manifested by the body coming towards the magnet. It will be necessary sometimes to bring the magnet within about one tenth of an inch distance of the swimming body,

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in order to perceive the attraction; in which case, as the body advances towards the magnet, this must be gradually withdrawn, taking care not to let them strike against each other; otherwise, after the impulse, the body, if hard, will generally recede. It must be also observed, to present the magnet to the body, when the latter is at rest.

A still smaller degree of attraction, than what may be observed by the use of water, may be discovered, by placing the given body to swim upon quicksilver, and by presenting the magnet to it, in which case it will move surprisingly nimble.

In this method, the following particulars must be minded, *viz.* the aperture of the vessel, in which the quicksilver is kept, must be at least six inches in diameter; otherwise, as the surface of the quicksilver descends near the sides of the vessel, and that curvature is proportionably greater in narrow vessels than in larger ones, the floating body, when the quicksilver is kept in a vessel of three or four inches, will be perpetually run-

ning towards the sides *. The quicksilver must be very pure; but, as it is very difficult to find it, or to preserve it pure, it must be frequently passed through a funnel of paper, *viz.* a piece of writing paper rolled up conically, and having a small aperture of about a fortieth of an inch in diameter; for, if the quicksilver be impure, the floating body will move with less facility upon it than upon water. The air about it must not be disturbed much, in order to keep the body without motion, in which state one of the poles of a strong magnet is to be presented on one side of it, in the same manner as when the experiment is tried on water; following the same precautions.

EXPERIMENT II.

To ascertain whether a given body has any magnetism or not.

This experiment requires exactly the same operations as the first, with only this difference, *viz.* that in this the given body,

* A common soup plate is very fit for this purpose.
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in case it has not magnetism sufficient to shew itself by a sensible degree of attraction when a piece of iron is presented to it, must be placed to swim upon water or quicksilver ; and, instead of the magnet, as used in the first experiment, a piece of soft and clean iron must be approached to it, with the same precautions ; for, if the body have any magnetism, it will be soon attracted by the piece of iron, which, for this experiment, must not be very long nor very heavy ; a piece of about half an ounce weight, and nearly an inch long, is very proper for the purpose.

EXPERIMENT III.

A magnetic body being given, to find out its poles.

Present the various parts of the surface of the magnetic body successively to one of the poles of a magnetic needle, and you will soon discover which parts of the given body are possessed of a contrary polarity, by the needle's standing perpendicu-

larly towards them. Then present the various parts of the surface of the same body to the other pole of the needle, &c.

In this operation, care must be taken not to bring the magnetic body too near the needle, for fear of changing its polarity. The distance at which such an effect will take place is various, according to the strength of the magnetic body ; so that it is impossible to prescribe it; but the operator will never mistake, if he keeps the magnetic body so far from the needle as just to affect it sensibly.

EXPERIMENT IV.

To obtain the same object as in the preceding experiment, by other methods.

If the given body have only two poles, they may be ascertained without the magnetic needle, viz. by sprinkling some iron filings upon it, and observing where the particles of the filings stand erect and perpendicular to the surface of the body ; for those places

places are the poles ; and, in order to distinguish the north pole from the south, place the said body on a piece of wood, and let it swim upon water, or tie it to a thread, and let it hang freely from it ; in which case, the body will soon shew its north pole, by turning it towards the north, and, of course, the opposite pole will be turned towards the south. In both those cases, *viz.* when the magnetic body is made to swim upon water, or suspended by a thread, it must be so placed as that its poles may lie horizontally.

This method, however, is not so precise as when a magnetic needle is used ; first, because it will not do when the given body has more than two poles, and, secondly, because, even when it has two poles only, they do not lie always in the same straight line, which passes through the centre of the body.

CHAPTER III.

Containing experiments concerning the action of a magnet on ferruginous bodies that are not magnetic.

PROPERLY speaking, the magnet has no action upon unmagnetic bodies; for, when a bit of iron, or other ferruginous body, is presented to it, the body becomes magnetic first, and then is attracted; so that in this chapter it is only meant to treat of the action of the magnet on those bodies, which were not magnetic before they were presented to it.

EXPERIMENT I.

To observe the effects produced by a magnet on soft iron.

Place a magnetic needle upon a pin stuck on a table, and, when the needle stands steady, place an iron bar of about eight inches long, and between a quarter of an inch and one inch thick, upon the table,

table, so that one end of it may be on one side of the north pole of the needle, and so near it as to draw it a little way out of its natural direction. In this situation, approach gradually the north pole of a magnet to the other extremity of the bar, and you will see that the needle's north end will recede from the bar more and more, in proportion as the magnet is brought nearer to the bar. If the experiment be repeated, with only this difference, *viz.* that the south pole of the magnet be directed towards the iron bar, then the north end of the needle will advance nearer and nearer to the bar, in proportion as the south extremity of the magnet is brought nearer to the iron.

The reason of this phenomenon is, that, by the approach of the north pole of the magnet, in the first case, the extremity of the iron bar, which lies next to it, acquires a south polarity, and, of course, the opposite extremity acquires the north polarity; in consequence of which, the needle is repelled, because magnetic poles of the same name repel each other; but in the second

case,

case, when the south pole of the magnet is brought near the bar, the end of the bar, which is next to it, acquires the north polarity, and the opposite end, acquiring the south polarity, attracts the north end of the needle.

If, whilst the pole of the magnet stands contiguous to one end of the bar, a small magnetic needle be presented within a certain distance to various parts of the surface of the latter, it will be observed, by the attraction and repulsion of the needle, that that half of the bar, which is next to the magnet, possesses the contrary polarity, and the other half the same polarity with the pole of the magnet that is applied to the iron.

The magnetic centre, however, or the limit between the polarities, is not always in the middle of the bar; it is generally nearer that end which is presented to the magnet. This difference is greater as the magnet is weaker, and the length of the bar increases; but when the bar exceeds a certain length, which depends on the strength of the magnet, then the bar

acquires several successive poles, *viz.* when the north pole of the magnet is contiguous to one of its extremities, that extremity becomes a south pole; a few inches farther on you will have a north polarity, then another south polarity, and so on. In this case, the first magnetic centre comes very near that end of the bar which stands next to the magnet, and other magnetic centres are formed between every pair of successive poles.

Those successive poles become weaker and weaker in power, according as they recede from that end of the bar which is contiguous to the magnet, so that, in a pretty extended bar, they quite vanish long before they come to the farther end of it; hence, if one pole of a magnet be applied to the end of a long bar, the other end of the bar will not thereby acquire any magnetism. This will happen, when a magnet, capable of lifting about two pounds weight of iron, is applied to one extremity of an iron bar, about one inch square, and above five feet long.

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On removing the magnet, the bar, if of soft iron, will immediately lose all its magnetism, otherwise will retain it a longer or shorter time, in proportion to its hardness.

If the above-mentioned experiment be tried with bars of the same dimensions, but of different degrees of hardness, it will appear, from the attraction or repulsion of the magnetic needle, that soft iron acquires a stronger magnetic power than hard iron, or steel, &c.

EXPERIMENT II.

To shew the action of the magnet on ferruginous bodies, by the repulsion and attraction of two pieces of wire.

Tie two pieces of soft iron wire, A B, A B, fig. 1. of plate II. each to a separate thread, A C, A C, which join at top, and, forming them in a loop, suspend them, by putting the loop on a pin, so that the wires A B, A B, may hang at some distance from the wall. Then bring the marked end, D, of a magnetic bar, which is usually the north pole, just under

under them, and it will be found, that the wires will immediately repel each other, as shewn in fig. 2. and this divergency will be greater when the magnet is brought nearer within a certain limit, and will decrease, according as the magnet is removed. The reason of this phenomenon is very easily deduced from the general laws of magnetism, *viz.* by the vicinity of the north pole D of the magnet, the extremities B, B, of the wires acquire the south polarity, consequently they repel each other; and the extremities A, A, both acquire the same polarity, namely the north, hence they likewise repel each other.

If, instead of the north pole of the magnet, the south pole be presented, the wires will repel each other in the same manner as before; but now their extremities B, B, will become north poles, and the extremities A, A, will become south poles.

On removing the magnet, the wires, if of soft iron, will soon collapse, having lost all the magnetic power; but if steel wires or common sewing needles be used, they will

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will continue to repel each other after the removal of the magnet, the magnetic power being retained by steel.

It has been said above, that, when the magnet is brought nearer and nearer to the wires, the divergency of the latter will increase, as far as *a certain limit*. The reason of this limit is the attraction between the magnet and the extremities of the wires, which, when the magnet comes too near, counteracts the repulsion between the extremities, B, B; so that the wires in that case stand as shewn in fig. 3. In fact, when the experiment is tried with steel wires, or needles, which retain the communicated magnetism after the removal of the magnet, their lower extremities will diverge more after having removed the magnet than when they stand very near it.

EXPERIMENT III.

To shew the action of the magnet upon ferruginous bodies, by means of four pieces of steel wire or sewing needles.

Take four pieces of steel wire, or four common sewing needles, tie threads to them,

them, and join them two by two, in the manner described in the preceding experiment; then bring the same pole of the magnet under both pairs, *viz.* one after the other, by which means they will acquire a permanent magnetism, and the wires of each pair will repel each other. After putting the magnet aside, if you bring one pair of wires near the other pair, so that their lower extremities may be all in one level, the four wires will repel each other, forming a square, because their lowest extremities are all possessed of the same polarity.

If instead of giving the same polarity to all the lower extremities, and the contrary polarity to all the upper extremities, you give one polarity to the lower extremities of one pair, and the contrary polarity to the lower extremities of the other pair; then, whilst those pairs are kept far from each other, the wires of each will fly away from one another; but if the two pairs be brought near, all the four wires will stick together in one bundle; the reason of which is, because the contrary polarities of both pairs,

pairs, being put near, will attract each other, and destroy the repulsion between the wires of the single pairs.

Instead of two, you may make several pairs of wires or needles, and, by giving one sort of polarity to the lower extremities of some, and the contrary polarity to the lower extremities of others, you may produce effects analogous to those described above.

EXPERIMENT IV.

Of the action of the magnet on iron filings.

Strew some iron filings upon a sheet of paper laid upon a table, and place a small artificial magnet among them ; then give a few gentle knocks to the table with your hand, so as to shake a little the filings, and you will find that they dispose themselves round the magnetic bar, in the manner represented by fig. 4. plate II. many particles clinging to one another, and forming themselves into lines, which, at the very poles, are in the same direction with

with the axis of the magnet, a little side-way of the poles they begin to bend, and then they form complete arches, reaching from a point in the north half of the magnet to a point in the other half, which is possessed of the south polarity.

This phenomenon, observed from time immemorial, has given occasion to various persons to believe, that there was a circulation of a fluid from one of the poles of every magnet to the other pole, in consequence of which the iron or steel filings were thus disposed round the magnet. At first sight, a person little skilled in magnetics would easily be induced to believe the said circulation of a fluid; but a little consideration will easily shew the absurdity of the supposition, because, if the fluid, of whatever nature it may be, did really circulate from one pole to the other, and had any action on the filings, these would be all driven toward that pole to which the moving fluid directed its course.

The true cause of the disposition of the filings is, their becoming actually magnetic,

netic, and their two extremities being possessed of different polarities. Suppose first, that only one oblong particle of iron be affixed to the various parts of the surface of the magnet; it is evident, from what has been said above, that on the poles this particle of iron A B, fig. 5, plate II. would stand perpendicular to the surface, because its farther extremity B, having the same polarity as the extremity C of the magnet, is equally repelled by it on every side, and is far from the influence of the other extremity D; on the sides near to the poles the said particle will stand inclined, because the farthest pole of the magnet begins now to act upon it; and on the middle of the magnet the wire will lie quite close to it, or, if it be kept at some distance, will lie parallel to the magnet, because the two poles of the magnet, being equidistant from the extremities of the iron particle, have an equal action upon it. Now, when there are many particles of iron, *viz.* the filings, near the magnet, those particles which touch its surface are rendered magnetic, consequently

consequently they attract other particles, and these being made also magnetic, attract others, and so on, forming strings of small magnets, which gradually decrease in power as they recede from the magnet. As each of those particles has two magnetic poles, by a little consideration it will appear, that the farthest ends of those strings or lines which proceed from the parts adjacent to one of the poles of the magnet, for instance, the north, are likewise possessed of the north polarity, and the farthest extremities of those strings which proceed from the parts adjacent to the south pole of the magnet, are possessed of the south polarity; hence, when they come sufficiently near, they attract the extremities of the former strings, and consequently form the curves delineated on the figure.

The shaking of the table in this experiment serves to stir the filings, by making them jump up a little way, and thus place themselves in the proper situation; otherwise, the action of the magnet, will not have power sufficient to dispose

properly those particles which stand at a considerable distance.

EXPERIMENT V.

To shew the action of the magnet on iron by means of a suspended body.

Tie a thread to one end of a bit of soft iron wire A B, fig. 6. plate II. about four inches long, and suspend it freely; place a stand of any sort in such a manner as to support a bar of soft iron C D, so as to let one of its extremities C be about three quarters of an inch distant from the lower extremity B of the wire. This done, if you bring either pole of a strong magnet E F under it, you will find that the end B of the wire A B will recede from the end C of the iron bar, because they are both possessed of the same polarity; but if the magnet be applied to the upper part of the wire, in the situation G H, then the end B of the wire will be attracted by the extremity C of the iron bar; because, supposing G to be the north pole of the magnet,

net, C being the extremity of the bar C D, that stands nearest to the north pole G, acquires a south polarity, and attracts the end B of the wire; because B being the part of the wire which stands remotest from the north pole G, acquires the same, namely, the north polarity.

EXPERIMENT VI.

To shew the effect of magnets on a crooked wire.

Let an iron wire of about a quarter of an inch in diameter, and four or five inches long, be bent somewhat like a gothic arch, *viz.* with a sharp corner in the middle, A B C, fig. 7, of plate II. and tie it fast to a cross bar, or let an assistant hold it with the corner downwards: then apply either pole of the magnet D E to one of its extremities A, and whilst the magnet remains in that situation, apply a piece of iron H, of no great size, to the corner C, and you will find that the iron remains suspended. Now, if another magnet be

applied to the other extremity B of the crooked wire, so that the pole G may be contrary to the pole E, the iron H will immediately fall off; but if the pole G be analogous to the pole E, *viz.* be both south, or both north, then the iron H not only will remain adhering to C, but the said corner will be capable of supporting a weight still greater than H. The reason of which is, because, in the former case, the extremities A B of the bent wire being possessed of different polarities, the corner C was the magnetic centre, where there is no attraction nor repulsion; whereas, in the second case, both extremities of the bent wire being possessed of the same polarity, the corner C was necessitated to acquire the contrary polarity; and in this case, the bent wire must have two magnetic centres, *viz.* one on each side.

EXPERIMENT VII.

Shewing in what circumstances a magnet can lift the greatest weight.

Take a magnetic bar, and find by trial an oblong piece of iron, about 4 inches long, and of a weight little greater than the magnet will support. It is plain that if you affix this iron to one pole of the magnet, the moment you remove your hand the iron will drop ; but if, before you remove the hand, you present another larger piece of iron just under the lower extremity of the former, and within half or three quarters of an inch from it, you will find that the magnet will then support that piece of iron which it could not support before, when a secondary piece of iron was not under it. In short, a magnet can lift a greater weight of iron from over another piece of iron, as an anvil, or the like, than from over a table.

The reason of which property is, that in the former case, the iron basis, or infe-

rior piece of iron, becoming itself in some measure magnetic, helps to increase the magnetism of the first piece of iron, and consequently tends to increase the attraction between it and the magnet; which does not take place when the iron is lifted from over a table, or something else which is incapable of acquiring any magnetism.

In order to render this property more intelligible, suppose that a piece of iron be affixed to the north pole of a magnet; it is plain, that by the action of the magnet, the part of it that stands next to the magnet has acquired a south polarity, and its other, or inferior extremity, has acquired a north polarity, the attraction being a consequence of this acquired magnetism, and being greater or smaller in proportion as that acquired magnetism is more or less powerful; consequently, whatever tends to increase that magnetism in the piece of iron, must likewise increase the attraction. Now, when another piece of iron is under the former, that other piece of iron, being within the sphere of action of the magnetic bar, becomes magnetic, and

the

the part of it which is contiguous to the north pole of the magnet acquires the south polarity; but this is contiguous to the lower end, which is the north pole, of the first piece of iron, therefore it must increase that north polarity, and, of course, the south polarity of the upper end of the first piece of iron, which stands next to the magnet.

In fact, if, instead of the secondary piece of iron, you put the south pole of another magnet at a little distance below the lower extremity of the suspended iron, you will produce the same effect, *viz.* will increase the attraction between it and the north pole of the first magnet; but if you present the north pole of the second magnet under it, then you will produce the contrary effect, *viz.* will weaken its magnetic power, and, of course, diminish the attraction.

EXPERIMENT VIII.

To shew the variable power of a magnet by suspending iron to it.

Suspend a magnet, in a place that is not much shook, and apply to it as much

weight of iron as it will just support *. Let a hook or a scale, like those used for a balance, be fastened to this iron. On the day following, you may put a little more weight into the scale, which the magnet will support. One or two days after, a little more weight may be added; and so on; the power of the magnet increasing daily: and, though this increase of power is neither unlimited nor very regular; being affected in some measure by the vicissitudes of heat and cold, &c.; yet, upon the whole, the power of a magnet will be considerably increased by this artifice.

It is very remarkable, that if, in the course of the operation, the iron were to drop from the magnet, on replacing it, you will find that the magnet will no longer support as much weight as it did a moment before, so that now you must diminish the weight, though in the course of the following days you may increase it

* For this purpose, the magnet, either natural or artificial, ought to be armed, or made in the shape of a horse-shoe; *viz.* so as to have the poles in one plane; in this form the effect being more conspicuous.

gradually

gradually again; hence, in placing the weights into the scale, or upon the hook, care must be taken not to give it any jerk, so as to cause the iron to fall off; otherwise a great deal of the work will be lost.

The reason of this experiment is, that the iron being rendered magnetic, tends to strengthen the magnetism of the magnet, in the same manner as any other magnet endeavours to render magnetic any ferruginous substance that is placed within its sphere of action. When the iron falls off, the magnet loses part of the acquired power, especially if the magnet had acquired more than its point of saturation, there having been removed the cause which kept it up; and when the iron is replaced, the magnet will not recover the lost power very readily, because there is required a considerable time to communicate a certain degree of magnetic power to a hard ferruginous substance, as the magnet is, especially when that magnetism must be communicated by the action of a proportionably weak magnet, like the iron weight.

According to Aepinus's hypothesis of
the

the magnetic fluid, this experiment is explained thus:—The magnetic fluid in a magnet is not equally dispersed through its substance; but one pole, or half of it, is overcharged and the other undercharged. There is a strong attraction between the undercharged part and the superfluous quantity of magnetic fluid in the overcharged part, and the restoration of the balance is in great measure prevented by the hardness or some other quality of the magnet. Now, when the iron is affixed to the magnet, it becomes magnetic, *viz.* that part of it which is contiguous to the overcharged pole of the magnet, becomes undercharged, and the opposite one becomes overcharged. In this situation, the undercharged part of the iron, endeavouring to draw the magnetic fluid of the magnet towards itself, accumulates or draws it still nearer to that overcharged pole of the magnet, and, on the other side, the overcharged part of the iron being contiguous to the undercharged pole of the magnet, tends continually to drive the magnetic fluid away from that undercharged pole of
the

the magnet ; but the power of the magnet, according to the hypothesis, depends on the unequal distribution of the magnetic fluid, therefore the action of the iron, by endeavouring continually to increase that unequal distribution, must increase the power of the magnet.

It follows from this experiment, that a magnet is apt to lose much of its power when kept without any iron affixed to it.

EXPERIMENT IX.

To shew the various effects produced by a magnet on different sorts of ferruginous substances.

Let several bars be made, of different sorts of iron and steel, but all of the same dimensions, *viz.* about five inches long, and half an inch thick ; then examine them, one by one, in the following manner :— Place a magnetic needle so that one pole of it may be about an inch distant from one end of the bar of iron or steel, but the

needle

needle and bar must not be in one direction ; then apply one pole of a magnet to the other extremity of the bar ; by the application of which, the needle will be moved from the situation in which it stood before. Thus repeating the operation with all the different bars, it will be found, that the needle is affected most when the bar is of soft iron, and least when it is of hard steel, or of the brittle sort of cast iron ; the other ferruginous substances affecting the needle in some intermediate degree between those two extremes.

This experiment plainly shews, that the magnet has more action upon soft iron than on any other state of that metal ; soft iron acquiring the greatest degree of magnetic power, and consequently disturbing the needle most. Hence it appears why a magnet attracts soft iron more powerfully than any other ferruginous substance, *viz.* because soft iron becomes more powerfully magnetic when acted on by the magnet.

In this experiment it will also be found, that those bars which become least magnetic,

netic, and of course affect the needle least, after the removal of the magnet will retain some magnetism; whereas the soft iron will lose it immediately; which evidently shews, that the difficulty of acquiring magnetism, and of retaining it when once acquired, is owing to the same cause, namely, the obstruction offered by the ferruginous substance to the free passage of the magnetic fluid, or of that power which produces the magnetic phenomena.

CHAPTER IV.

Of the action of magnets on each other.

EXPERIMENT I.

To shew the action of a magnet on a magnetic steel wire.

TAKE a soft steel wire, like A B, fig. 8, of plate II. about five inches long, and a quarter of an inch thick, and give it some magnetism, by placing it between two magnetic bars for a minute or two. This done,

done, find its magnetic centre C, according to the experiment described in the second chapter; then lay it upon a table, and put a magnetic bar, D E, near it, so that their north poles may be towards each other. In this situation, if you examine the wire A B, by means of the magnetic needle, you will find that the action of the magnet D C has removed the magnetic centre C farther from the end B; and the nearer the magnet is approached to B, the nearer will the magnetic centre C come to the extremity A. At last the end B of the steel wire will become a south pole, the north pole will be removed towards C, and another magnetic centre will arise between those two poles. In this experiment, a great deal of variety is occasioned by the various strength of the magnet, the length and softness of the steel bar, and the distance between the one and the other.

1. If the steel bar be very long, it will acquire several successive poles, and the original magnetic centre C, will not come proportionably so near the extremity A as when the wire is shorter.

2. If

2. If the wire A B be very short, by the approximation of the magnet, its poles will be reversed, so that B, which was the north pole, will now become south; and the extremity A will become the north pole.

3. If the power of the magnet D E, be so weak, as to come nearly to an equality with the magnetic power of the wire A B, then they will have an equal power upon each other; and the consequence will be, that the north poles of both will be a little removed from the extremities B and D; provided the substance of the magnets is equally soft.

4. By a gradual approximation of the strong magnet D E, to the steel wire A B, the extremity B of the latter must have its polarity first diminished, then annihilated, and lastly reversed.

From an attentive consideration of the above-mentioned particulars, it will appear, that, before the pole B is changed, the two magnets must exert a repulsion against each other; that when the polarity of B is annihilated, the two magnets can

neither attract nor repel each other; and, lastly, that when the extremity B has acquired a south polarity, the two magnets must attract each other.

In Case 3, the two magnets can have little or no power on each other; so that no attraction nor repulsion will take place between them.

EXPERIMENT II.

To shew the action of both magnetic poles, of two magnets, on each other.

What has been said in the preceding experiment, with respect to one magnetic pole, will now be easily applied to explain the action of both poles of one magnet, on the analogous poles of another magnet.

Let C E D, A F B, fig. 9. of plate II. be two semicircular magnets, and let their poles of the same name be approached towards each other; A, C being north poles, and B, D south poles. The consequence of this approximation will be various, according to the various strengths of the

the magnets, and the distance between them. Thus, if they be unequal in power, on their being gradually brought near to each other, the poles of the weak one must be gradually weakened, in which case, a repulsion is exerted between the magnets ; then they are annihilated ; in which case, no attraction nor repulsion will take place ; and, lastly, they will be changed, and then the two magnets will attract each other.

If the magnets be equal in power, and of a very hard nature, they will always repel each other, because the poles of neither of them are destroyed or reversed ; but, if equal in power, and of a softer nature, then, when brought sufficiently near, will destroy each other's polarity, and, of course, no attraction nor repulsion will take place.

In this experiment, the magnetic centres, E and F, will not be removed from their places, the action of the two poles being equal on both sides ; so that the only thing that can happen, is the generation of more magnetic centres, and, of

course, of more magnetic poles, the number of which depends on the length, hardness, and power of the magnets,

EXPERIMENT III.

To shew the action between the contrary poles of two magnets.

In the two preceding experiments, the homologous poles of the magnets were opposed to each other ; but, if they be repeated, by presenting the south poles to the north poles, the phenomena will be as follows, *viz.*

The magnetic poles of each magnet will be strengthened, the nearer they are approached to each other ; the attraction will increase in the same proportion, and it can never be changed into repulsion. But, as the degree of attraction depends on the strength of the contrary poles, every thing else remaining the same, and as the increase of the polarity of one magnet from the action of another magnet, principally depends

pends upon the softness of one of the magnets, it follows, that, in certain circumstances, a weaker magnet may be attracted more powerfully than a stronger one.

In order to render this kind of paradox very evident, let two small magnetic bars be made, exactly of the same dimensions, but let one be made of the hardest, and the other of the softest steel. Let the latter have a very weak magnetic power, but the former a greater power. This done, if you apply those magnets singly, and alternately, to a third magnet, considerably more powerful than either of them, you will find, that the weak magnet, *viz.* that of soft steel, will be attracted more powerfully than the other; the reason of which is, that the soft steel magnet will have its poles rendered considerably stronger by the vicinity of the third magnet, and that on account of its softness, though, for the very same reason, its power will be soon diminished when removed from that sphere of action; whereas the magnet of hard steel, though its poles be increased a

little by the action of the third magnet, yet, on account of its hardness, they will not be increased to such a degree as those of the soft steel one.

It appears therefore, from this and the two preceding experiments, that when two magnets are approached near each other, they may repel, attract, or not act at all on one another, according to the various enumerated circumstances ; that the repulsion at a distance may be changed into attraction, by bringing the magnets nearer ; that the attraction taking place when the magnets are within a certain distance of each other, may be changed into repulsion by increasing that distance * ; and that a

* Thus when two magnetic bars, pretty long, but not very hard, and of different powers, are placed in the same direction, with the north pole of one contiguous to the north pole of the other, the weak magnet will have its north pole changed into a south pole for a short way, in consequence of which, an attraction will take place ; but when the magnets are removed farther off, then the original south extremity of the weak bar will restore the north polarity of the opposite extremity, and, consequently, a repulsion will ensue.

weaker magnet, in certain cases, may be attracted with greater force than a stronger one ; this law remaining certain and unaltered in any case, *viz.* that the poles of the same name repel, and those of a different name attract, each other ; so that, when an attraction takes place between those parts of ferruginous substances, which were before possessed of the same polarity, it may be concluded, that the polarity of one of them has been actually changed.

EXPERIMENT IV.

To increase or diminish the attraction between a magnet and a piece of iron, by the action of another magnet, equal in power to the former.

Place a magnetic bar, A B, fig. 10. of plate II. so that one of its poles may project a short way beyond the table, and apply an iron weight, C, to it ; then take another magnetic bar, D E, like the former, and bring it parallel to, and just over the other, with the contrary poles towards

each other ; in consequence of which, the attraction of B will be diminished, so that the iron C, if very heavy, will drop off, and the magnet can only support a smaller piece of iron. In short, this attraction will be diminished, and, when the magnets come quite into contact, provided they be of an equal power, the attraction will entirely vanish ; but if the experiment be repeated, and the homologous poles of the magnets be approached to each other, then the attraction, instead of being diminished, will be increased.

As the attraction between the iron and the magnet is owing to the iron acquiring a different polarity, it follows, that whatever contributes to increase that different polarity, increases likewise the attraction, and, on the contrary, whatever diminishes or destroys that different polarity in the iron, must likewise diminish or destroy the attraction. Therefore, when the extremities E and B of the magnets are both north poles, or both south poles, that part of the iron which is next to B becomes more and more strongly possessed of the contrary polarity,

larity, the more the magnets are approached; but when B and E are poles of different name, they will prevent the iron acquiring any polarity, because, if the action of one tends to communicate to it a north polarity, the action of the other will endeavour to communicate a south polarity to the same extremity of the iron.

EXPERIMENT V.

To increase or diminish the attraction between a magnet and a piece of iron, by the action of another more or less powerful magnet.

If the preceding experiment be repeated with magnets of unequal power, for instance, the magnet D E be much more powerful; on approaching the two magnets to each other, it will be found, that the greatest degree of attraction, when the contrary poles are towards each other, and the entire destruction of the attraction, when the homologous poles are towards each other, will take place before the magnets come into contact; the reason of which the ingenious reader may easily understand, after what has been said before.

EXPERIMENT

EXPERIMENT VI.

To shew the generation of the poles, and of the magnetic centres, in the parts of a broken magnet.

Take a magnetic bar A B, fig. II. of plate II. of very hard steel, and having only two poles, A and B.—A magnetic bar about 6 or 8 inches long, and about a quarter of an inch in diameter, answers very well for this experiment. The magnetic centre of this bar will be in its middle, C, or very little distant from that point. Now if, by a smart stroke of a hammer, you break off F B, about one third part of the magnet, it might be expected the part F B, which before the fracture was all possessed of one polarity, for instance, the north, would now continue so; but upon examination it will be found, that that part of the fragment, which was contiguous to the fracture, has acquired the contrary polarity, namely the south, and a magnetic centre E will be generated.

It has been observed, that the magnetic centre of this fragment, at first, is always nearer to the fracture F, but in time it advances nearer to the middle of the fragment. The original centre C of the other piece, A F, after the fracture, will likewise advance nearer to the middle of it.

This experiment may be diversified in the following manner:—A steel bar, of about six inches long, and a quarter of an inch thick, being made quite hard, may be broke in two unequal parts; these parts may be joined together, and pressed against each other, so as to make them look as if the bar had not been broke; in this situation, it may be rendered magnetic by the application of very powerful magnets to its extremities; after which, on examination, the whole bar will be found to have two poles on its extremities, and one magnetic centre in its middle; but if the parts be separated, each will be found to have two poles and a magnetic centre, &c.

What has been here said of artificial magnets, has been found true with natural magnets also, and with magnets having more

more than two poles; in short, if a magnet be broke in several pieces, every fragment is a complete magnet, having at least two poles and one magnetic centre; nor was a piece of a magnet ever produced which had only one polarity.

EXPERIMENT VII.

Of removing the magnetic centre in a magnet.

The same means, which facilitate the transition of the magnetic power from one part to the other of a ferruginous body, have likewise the power of removing the magnetic centre, in magnets which have it not in their middle, and to make it approach nearer to that point; hence this may be effected various ways, *viz.* by striking a magnetic bar repeatedly, by heating it, by hard rubbing, &c.; but it must be considered, that those very means generally tend to weaken the magnetism of the magnet; therefore they ought not to be applied beyond what may be necessary to produce a sensible removal of the magnetic centre from its original place.

CHAPTER V.

Of communicated magnetism, or of the various methods of making artificial magnets:

EXPERIMENT I.

To make a piece of iron acquire the magnetism from the earth.

TAKE a bar of soft iron, about two or three feet long, and between half and two inches thick (some kitchen pokers are very fit for this experiment) and place it straight up *. Then place a

* In a proper manner of making the experiment, the iron bar ought to be placed in the magnetical line, viz. in the direction of the dipping needle; but, as few persons are furnished with a dipping needle, and many may be desirous of performing this curious experiment, it will be sufficient for those persons to place the bar straight up, when they are in higher latitude than 40° north or south, but to place it horizontally when they are nearer to the equator than the above-mentioned degree of latitude.

magnetic needle on a pin, and, holding the pin in your hand, present the needle to the various parts of the bar from top to bottom, and you will find, that in this island the lower half of the bar is possessed of the north polarity, capable of repelling the north and of attracting the south pole of the needle, and the upper half is possessed of the south polarity, capable of repelling the south and of attracting the north pole of the needle. The attraction is strongest at the very extremities of the bar, it diminishes as it recedes from them, and vanishes about its middle, where no one pole of the needle is attracted in preference to the other. In short, in that situation, the iron bar is as much a magnet as any piece of iron that stands within the influence of a magnet *.

If you turn the bar top-side down, the extremity of it, which was south pole when

* Besides its power on the needle, if the iron bar be not very short, it will even attract small pieces of iron, as filings, &c. that are placed near its extremity.

it stood uppermost, will now become north pole, and the other extremity will become south pole.

In the southern parts of the world, the lower part of the bar is a south pole ; or, to be more explicit, when, in any part of the world, the bar is situated in the magnetic line, the extremities of the bar will acquire the polarities corresponding to the nearest poles of the earth.

EXPERIMENT II.

To fix in an iron bar the magnetism which is communicated to it by the earth.

The very soft iron acquires the greatest degree of magnetic power in the shortest time, but loses it with the same quickness ; so that, if the preceding experiment be performed with a bar of that sort of iron, the magnetism communicated to it by the earth will not be permanent ; but if it be made red-hot, and be left to cool in the magnetic line, or if it be repeatedly struck with a hammer, whilst standing in the

the magnetic line, it will thereby acquire a small degree of permanent magnetism; which power, however either by leaving the bar for some time in an improper situation, or by inverting and striking it again, will be soon destroyed.

When the iron is somewhat harder, the acquired magnetism lasts much longer; though a longer time, or longer operation, be required in order to render it magnetic.

As the constant action of a weak magnet on a ferruginous body continually tends to increase the magnetism of that body; so the iron bars, which are left in the direction of the magnetic line for a considerable time, become continually more strongly magnetic, and the acquired power becomes more permanent.

The reason why iron, by long standing; by hammering, &c. acquires a permanent magnetism from the earth, whereas by the mere position, in a short time, the power is not at all permanent, seems to be the unequal texture of the iron: suppose,

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for instance, that a piece of iron is composed of hard and soft particles, or of some, through which the magnetic power moves very easily, and others, through which it moves very slowly. The former then, of those particles, acquire the magnetism at first from the earth, and lose it very easily; but by continuing in the same position, or by being softened, &c. the hard particles gradually acquire magnetism from the former, and, having once acquired it, retain that power for a long time. It is, besides, very probable, and, in certain circumstances, actually proved, that some sort of iron becomes harder by being kept long exposed to the atmosphere.

EXPERIMENT III.

To communicate a permanent magnetism to a ferruginous body, by means of an iron bar, whilst this is rendered magnetic by the earth.

The simplest method of producing this effect, is described in the Philosophical

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Transactions,

Transactions, by Mr. Arnold Marcel * ; part of whose paper I think it not improper to transcribe in this place, it being the first method of the kind that I find published.

" In the year," says he, " 1726, making several further observations about the magnetical force, which I found in great pieces of iron, I made use of a large iron vice, about 90 lb weight, in which I fixed a small anvil of about 12 lb. Upon the bright surface of this anvil I laid the steel, to which I would give the virtue, in a position of north and south, which happened to be in a diagonal of the square surface of the anvil ; then I took a piece of iron, one inch square, and 33 inches long, of about eight lb. weight, having at one end the figure here represented (fig. 12. plate II.) brightly polished at A, and taper at the other end : Then I held fast down the piece of steel upon the anvil with one hand, and with the other

* Martyn's Abridgment, Vol. VI. Part II. p. 278.

" I held

" I held the iron bar aforesaid perpendicular, with its point A upon the steel, and, pressing hard, I rubbed the steel with the iron bar towards me, from north to south, several strokes, always carrying the bar far enough round about, to begin again at the north, to prevent the drawing back of the magnetical force. Having thus given 10 or 12 strokes, I turned the steel upside down, leaving it in the same position as to north and south, and, after rubbing it and turning it, till I rubbed it about 400 times, it received, by degrees, more and more strength, and at last had as much as if it had been touched by a strong load-stone. The place where I began to rub, was always that which pointed to the north when the needle was hung, the end where I had ended the stroke turning to the south. Sometimes it has happened, that in a few strokes I gave the steel its virtue; nay, even in the very first stroke, one may give a great deal to a small needle. This way I have given the magnetical virtue

" to needles of sea-compasses, made of
" one piece of steel, so strongly, that
" one of the poles would take up $\frac{1}{2}$, and the
" other a whole ounce of iron : although
" these needles were anointed with linseed
" oil, which made a hard coat, to keep
" them from rusting, yet they kept the
" virtue ; but in strengthening these sort
" of needles, I rubbed by turns first to the
" right and then to the left side.

" The same way I brought the virtue
" into the point of a knife, so that it
" would sustain $1\frac{1}{2}$ ounce.

" I brought the said virtue into four
" small pieces of steel, each one inch long,
" and $\frac{1}{16}$ inch broad, as thin as the spring of
" a watch. These four pieces I joined
" together, as into an artificial loadstone,
" weighing 18 grains *Troy*, and then it did
" draw up and sustain an iron nail, which
" weighed 144 grains *Troy*. This artificial
" loadstone has now these six years been
" tumbled about, and been lying among
" iron and steel, and in any position, and
" yet it has rather got more than lost
" any of its virtue.

The

“ The magnetical virtue being thus brought into iron or steel, I have farther observed, that that end where the stroke was begun, would draw to the north, and where the stroke ended, to the south, in whatever situation the steel had been laid upon the anvil to give it the virtue. I took a piece of steel, and rubbed it from one end to the middle, and then from the other end to the middle, and found it had two north poles, one at each end, and the middle a south pole.

“ Further, beginning to rub from the middle towards each end of another piece of steel, I found it to have at each end a south pole, and in the middle a north pole.”

A very easy way of giving magnetism to a small piece of soft steel, is the following:—Take two pokeres of soft iron, or two iron bars, of about an inch square, and more than 3 feet in length, keep them in the magnetical line, or (if in this island) perpendicularly, as shewn in fig. 13. of plate II. Then let the piece of steel C B be either fastened

to the edge of a table, or be held by an assistant; and, placing the lower extremity of the bar A B, and the upper extremity of the bar C D, both on the same side, and in the middle of the steel, stroke the steel from the middle towards its extremities, moving the end of the bar C D from the middle of the piece of steel towards its end C, at the same time that the end of the bar A B is moving from the middle of the piece of steel to its other extremity B, and when the bars are arrived to the said extremities, remove them from the steel, and apply them again to the middle, and so on; thus stroking the piece of steel about 40 or 50 times on every side, will give it a considerable degree of magnetism.

It is evident, that if in this experiment, when the iron bars are arrived to the extremities of the steel, you bring them back to the middle of it, by drawing them along the surface of the steel, the experiment will not succeed, because the magnetic power communicated by their rubbing the steel in one direction, will be destroyed by their contrary motion.

EXPERIMENT

EXPERIMENT IV.

*To construct artificial magnets, after the manner of Mr. Canton *.*

Let six bars be made of soft steel, about 3 inches long, $\frac{1}{4}$ inch broad, and $\frac{1}{20}$ inch thick. Let also six other steel bars be made quite hard, and about six inches long, half an inch broad, and one eighth thick. Each of those sets of bars must have two pieces of soft iron, called supports or conductors, both equal to one bar of the respective set. One end of each of these 12 bars must be marked with a line, which end is to become the north pole. Have ready also an iron poker and tongs, that have been long in use,

Place the poker nearly upright, or rather in the magnetical line, with its point downwards ; and let one of the soft steel bars be tied, by means of a thread, to the middle of it, and with the marked end downwards ; then with the lower end of the tongs, held also in an upright position, or in the mag-

* Phil. Trans. for the year 1751 and 1752.

netical line, stroke the steel bar from the marked end upwards, about 10 times, on both sides, which will give it power enough to keep suspended a small key. Thus communicate the magnetism to four of the small bars.

This done, lay the two other small bars on a table, parallel to each other, about a quarter of an inch asunder, and between their iron conductors, A B, C D. fig. 14. of plate II.; taking care to place the marked end of one of the bars on one side, and the marked end of the other bar on the opposite side. Now place the four bars, already made magnetic, in the form shewn in fig. 15. viz. two with their north poles downwards, and the other two with their south poles downwards. The two of each pair must be placed breadth to breadth, and the two pairs being put contiguous to each other at top, must be kept open to a small angle by the interposition of some hard substance I. This sort of compound magnet, formed of the four bars, must be placed with its aperture on the middle of one of the soft bars A C, taking care to let

let the south poles H be towards the marked end of the bar A C, and the north poles F towards the other extremity. In this position, the compound magnet must be slid from end to end of the said bar, *viz.* when the poles H are arrived at C, move the compound magnet backwards the other way, till the poles F come to A, &c. Thus stroke the lying bar four times, ending at the middle; from whence take up the compound magnet, and remove it to the middle of the other lying bar B D, taking care, as above, to let the south poles be towards the marked end of the bar; rub this in the like manner; then turn the bars A C, B D, with the sides that stood towards the table upwards, and repeat the operation on those other sides. This being done, take up the two bars A C, B D, and let them form the inner two of the compound magnet; and place those which were before the two outside ones, between the pieces of iron, or conductors, and rub them with the compound magnet formed out of the other four bars, in the same manner as before. This operation

ration must be repeated till each of the six bars has been rubbed four or five times, by which means they will acquire a considerable degree of magnetic power.

When the small bars have been thus rendered magnetic, in order to communicate the magnetism to the large bars, lay two of them upon the table, between their two conductors, or pieces of iron, in the same manner, and with the same precautions, as were used for the small bars; then form a compound magnet with the six small bars, placing three of them with the north poles downwards, and the three others with their south poles downwards. Place those two parcels at an angle, as was done with four of them, the north extremity of one parcel being put contiguous to the south extremity of the other, and with this compound magnet stroke four of the large bars, one after the other, about twenty times on each side, by which means they will acquire some magnetic power.

When the four large bars have been so far rendered magnetic, the small bars are laid

laid aside, and the large ones are strengthened by themselves, in the same manner as was done with the small bars.

With some sort of steel a few strokes are sufficient to impart to them all the power they are capable of retaining; other sorts require a longer operation; and sometimes it is impossible to give them more than a just sensible degree of magnetism.

In order to expedite the operation, the bars ought to be fixed in a groove, or between brass pins; otherwise the attraction and friction between the bars will be continually deranging them, when placed between the conductors.

After what has been said in the preceding pages, the reader may easily comprehend the reasons of the operations here described, for constructing artificial magnets.

EXPERIMENT V.

To communicate magnetism by means of two magnetic bars.

It may be readily understood, that in order to communicate magnetism by means of two magnetic bars, the operation goes on much in the same manner as in the preceding experiment; but as it is more convenient to use two bars, and as the observations which may be made on the use of them are also applicable to the other methods of communicating magnetism, I thought proper to treat of it apart.

In order to communicate magnetism to a steel bar, to the needle of a compass, &c. place the bar or needle A B, fig. 16. plate II. upon a table; then place the two magnetic bars C D, E F, straight up upon A B, at a little and equal distance from the middle of the bar A B, and in such manner as the south pole D of one of the bars may be nearest to that end of the bar A B, which is required to become the north

pole, &c. then these two bars must be slid gradually towards one extremity of the bar, keeping them constantly at the same distance from each other ; and when one of the magnetic bars, for instance C D, is arrived at A, then they must be slid the contrary way, till E F arrives at B ; and thus the bar A B must be rubbed a greater or smaller number of times till it will be found, by trial, to have acquired a considerable power. When the magnetic bars are powerful, and the bar A B is of very good steel, and not very large, a dozen of strokes are fully sufficient. — When the magnetic bars are to be removed from the bar A B, care must be had to bring them to the same situation where they were first placed, *viz.* at a little and equal distance from the middle of the bar A B, and then they may be lifted up.

In this operation the effect of the bars may be improved several ways, which will be found necessary when the bar A B is proportionably large, and it is required to give it the greatest possible power. This may be effected, first, by joining the magnetic

netic bars at top, interposing a piece of wood or other substance, except iron, to keep them apart, as shewn in fig. 17; for in this manner, the upper poles of the bars being contiguous, will tend to strengthen each other, and, of course, their lower poles will also be strengthened. Secondly, by placing the bar, to be rendered magnetic, between two bars of soft iron, or two other magnets, as shewn in fig. 17. or in the manner directed in the preceding experiment. Thirdly, the magnetic bars may be inclined the contrary way, after the manner used by Mr. Aepinus, fig. 18. plate II. so that the magnets C D, E F, may make an angle of about 15 degrees with the bar A B.

The bar A B may, in the same manner, be rendered magnetic by means of an armed magnet, as shewn in fig. 19. or by a horse-shoe magnet, as shewn in fig. 20. placing both the poles of the magnet in contact with the bar, &c.

In all those methods the bar to be rendered magnetic must be stroked on every side; and in order to let the magnetic centre fall just in its middle, care must be had

to

to stroke one half of the bar just as often as the other half.

Whenever a steel bar, or in general a piece of ferruginous substance, is rendered magnetic by applying two bars, or whenever two magnetic poles are applied to it at the same time, as used in this and the preceding experiment, the operation is usually called the *double touch*, in distinction from the *single touch*, which is when only one magnetic pole is applied to it.

EXPERIMENT VI.

To communicate the magnetic power to crooked steel bars.

Artificial magnets are frequently made in the shape of a semicircle, or like a horse-shoe, for the sake of bringing both poles in the same plain. These are rendered magnetic in the same manner as the straight bars, excepting only, that the magnetic bars which are used for it, must follow the curvature of the steel bar; thus, if it be required to render magnetic the piece of steel A B C, fig. 21. plate II.

place

place it flat upon a table, and to its extremities apply the magnets D F, E G; joining their extremities F G with the conductor or piece of soft iron F G. Then apply the magnetic bars H, I, to the middle of the piece A B C, and stroke it with them, from end to end, following the direction of the bent steel; so that on one side of it the magnetic bars may stand in the direction indicated by the dotted representation L K.—In this manner, when the piece of steel has been rubbed a sufficient number of times on one side, turn the other side upwards, and repeat the operation till it has acquired a sufficient degree of magnetism.

In this operation the same precautions must be followed as were recommended for the method of communicating the magnetism to straight bars, *viz.* the magnets D F, E G, as well as the magnets H, I, must be placed so that their south poles must be towards that extremity of the bent steel which is required to be made the north pole, and their north poles towards the other extremity. The mag-

nets

nets I, H must be first placed on the middle of the bent steel; and after having drawn them over one leg of it as often as over the other, in order to let the magnetic centre fall just in the middle of the bent steel, they are removed, &c.

EXPERIMENT VII.

To communicate magnetism by the application of only one magnetic pole.

If a person have only one magnetic bar, or a terrella, with which he wished to give magnetism to a needle or other bar, the only way of effecting it is, to apply one pole of the terrella, or magnetic bar A B, fig. 22. plate II. to one extremity C of the needle, and to draw it all along the surface of it till it reaches to the other extremity D; then the magnet being removed must be applied again to the extremity C, and must be drawn over the needle as before. Thus the needle must be rubbed several times, by which means

it will acquire a considerable degree of magnetism.

It must be observed, that the extremity of the needle which the pole of the magnet touched last, acquires the contrary polarity. Thus, in the present instance, if B be the north pole of the magnet, then the extremity D of the needle will afterwards be found to have acquired the south polarity, and the other extremity C, the north.

In this operation it is evident, that after the first stroke, when the magnet is applied again to C, this extremity, having acquired the north polarity, will have that power destroyed by the vicinity of the north pole B of the magnet; so that it seems that every stroke undoes what was done in the preceding; however the fact is, that by repeating the strokes the power is increased; but, in general, this method will never be so advantageous as when more than one magnetic pole is used; hence it ought not to be used excepting in case of necessity, *viz.* when one has only one magnetic bar or terrella.

EXPERIMENT

EXPERIMENT VIII.

To shew the disadvantages arising from the improper use of magnets of different power, and of steel not properly hardened.

After having communicated the magnetic power to a steel bar, by means of a given magnet, examine its power; then take a weaker magnet, and with it rub the steel bar again in the same direction as was done before; using the same pole, and, in short, following exactly the same operation; after which it might be expected, that the magnetic power of the steel bar was increased; but, on the contrary, it will be found that its power is diminished, being now not stronger than if the steel bar had been rendered magnetic by the second weak magnet alone.

In this experiment it is required that the second magnet, though weaker than the first, yet be not so strong as to render the steel magnetic to its point

of saturation, *viz.* as much as it can hold; for in that case the difference between the effects of the two magnets could not be observed.

It appears, therefore, that if in communicating magnetism, it be advantageous to use weak magnets first, and then stronger ones, yet the contrary is detrimental.

In respect to the soft nature of the steel that is used for artificial magnets, it must be observed, that soft steel, or iron, besides its losing the magnetic power very easily, is subject to acquire more than two poles. This may be observed in the following manner:—Take two wires, about fourteen inches long, and an eighth of an inch in diameter; and let one be of steel, quite hard, and the other of very soft steel, or of iron, but not of the softest sort; then, by means of magnetic bars, render these two wires magnetic, one after the other, treating them both alike, and it will be generally found, that the wire of hard steel will have acquired only two magnetic poles, one at each extremity; whereas the other wire will have more than two poles.

EXPERIMENT IX.

To improve natural magnets.

The same means by which steel bars are rendered magnetic, or are strengthened in power, may be applied to increase the power of a weak natural magnet, or to render magnetic certain iron ores; but as the natural magnets are in general very short, one can seldom do more than place them between strong magnetic bars; however, when they are sufficiently long, besides putting them between magnets, they must be rubbed with other magnetic bars, in the same manner, and using the same precautions as were recommended in the methods of making artificial magnets.

For this operation it is always proper to remove the armature from the natural magnets if they have any, as is generally the case.

In the following diagram given at left will be seen a plan of a small frame made of wood, with a bottom board of thin pine boards, and a top board of thin pine boards, all mounted upon a base of old stones, so as to give it a slight elevation.

CHAPTER VI.

Of the use of the Magnetic Instruments.

THE magnetical instruments may be reduced to three, *viz.* the magnetic bars, the compass, and the dipping needle. There needs nothing more be said, in particular, relating to the magnetic bars; their use in communicating magnetism to other bodies, and in discovering the presence of iron in various substances, having been already sufficiently examined.

As to the use of the simple compass, the reader can hardly expect any farther explanation; for as its office is to place itself always in the same position, it serves to shew the bearing of different places, especially where there is no other fixed object to guide the observer. It may be only proper to remark, that at sea, when the vessel is very much agitated, and of course the card of the compass is not steady, the best way of determining the true direction of the vessel, is to take a mean between the extremes

extremes of the vibrations of the needle. Thus, suppose the card was to vibrate, so that its north and east points were the extremes of the vibrations, *viz.* those points did alternately coincide with the fixed line in the box, then the true direction of the vessel would be *N. E.* or nearly so.

But as the magnetic needle seldom points due north and south, the bearings of places cannot be accurately known by the compass, unless its declination be ascertained; which is easily known on land, by means of a variation compass placed in the true meridian of the place; but in order to ascertain it at sea, by means of the azimuth compass, there requires an observation of a celestial object, and some calculation. I shall now add the rules necessary to perform this operation, but without going any farther than the mere operation; it being incompatible with the nature of this work to explain the astronomical and mathematical principles upon which those rules depend.

DEFINITIONS.

The *true amplitude* of a celestial object, is an arch of the horizon contained between the east or west points of the horizon, and that point of the said horizon which the centre of that celestial object cuts in its rising or setting.

The sun's amplitude is reckoned eastward in the morning, and westward in the afternoon; and its quantity is accounted from the east or west points, towards the north or south. Thus, if the sun, in setting, were to pass two degrees northward of the west point of the horizon, then it is said that the sun's western amplitude is two degrees north.

The *true azimuth* of a celestial object is an arch of the horizon intercepted between the north or south point, and that point where a plain, passing through the zenith and the celestial object, cuts the horizon.

The sun's azimuth is reckoned eastward
in

in the morning, and westward in the afternoon.

It is usually estimated from the south, or from the north, according as it is nearer to the one or to the other of those points. Thus, if it be found, by observation, that the plain, which passes through the zenith and a star, cuts the horizon just midway between the east and the south, then it is said that the star's azimuth is 45° eastward of south.

The *magnetic amplitude* of a celestial object is its bearing by the compass when in the horizon.

The *magnetic azimuth* of a celestial object is its bearing by the compass when above the horizon.

The variation is found by comparing together the true and magnetic amplitudes or azimuths of celestial objects.

PROBLEM I.

To observe at sea the magnetic amplitude of a celestial object with the azimuth compass.

Place the compass on a steady place, from whence the horizon may be clearly seen ; and, looking through the sight vanes of the compass, turn the instrument round till the centre of the sun, or other celestial object, may be seen through the narrow slit which is in one of the sight vanes, exactly on the thread which bisects the aperture in the other sight vane ; and when the centre of the celestial object, whether rising or setting, is just in the horizon, push the stop, in the side of the box, so as to stop the card, and then read the degree of the card which stands just against the fiducial line in the box, which is the amplitude sought.

In this operation some allowance must be made for the height of the observer's eye above the level of the sea.

PROBLEM

PROBLEM II.

To observe at sea the magnetic azimuth of a celestial object with the azimuth compass.

Situate the instrument in a proper place, as before, and looking through the narrow slit in one of the sight vanes, turn the box round, till the centre of the celestial object, when above the horizon, may be seen to coincide with the thread in the slit of the other sight vane, or till the shadow of that thread, when the sun is observed, falls exactly along the line of the index, and in the same instant stop the card; then read the degree, as before, which is the azimuth sought.

When the vessel is very much agitated, this, or the preceding observation, is best performed by two persons, in the following manner; viz. let one look through the sights, and turn the box till the centre of the sun coincides with the thread, taking care to keep a constant sight of the coincidence, notwithstanding the motion of the

the vessel. He must then signify that coincidence by word or sign, to the other person, who must, at the same time, observe what degree of the card is against the fiducial line in the box. When the card vibrates very much, the observer must take the middle degree between the extremes of the vibrations, as mentioned in the beginning of this Chapter.

N. B. At the same instant in which the magnetic azimuth of a celestial object is observed, the altitude of the same object must be taken with a sextant.

PROBLEM III.

The latitude of the place of observation, and the declination of a celestial object, being given, to find the true amplitude of that object.

The analogy is the following, viz. the cosine of the latitude is to the radius, as the sine of the declination is to the cosine of the amplitude. The first, second, and third members of this analogy being known,

known, the fourth, *viz.* the amplitude, is found by the common rule of proportion, which, by the help of a logarithmical table, is performed thus:

Add the logarithm of the sine of declination to the logarithm of the radius, and from the sum subtract the logarithm of the cosine of the latitude. The remainder is the logarithm of the cosine of the amplitude.—For instance, in latitude $38^{\circ} 25'$ north, the sun's declination being $18^{\circ} 59'$; required its amplitude?

$$\text{Log. sine of } 18^{\circ} 59' = 9,51227$$

$$\text{Log. of radius } = 10,00000$$

$$\text{Sum } = 19,51227$$

$$\text{Log. cof. of } 38^{\circ} 25' = 9,89405$$

$$\text{Remainder } - - - = 9,61822$$

which is the logarithm of $24^{\circ} 32'$, the amplitude required; which is of the same name with the given declination, *viz.* north when the declination is north, as in the present instance, and south when the declination is south.

PROBLEM IV.

The latitude of the place of observation, the declination of a celestial object, and its altitude, being given; required the true azimuth of that object.

If the declination and latitude be both north, or both south, call the codeclination A; but if they be one south, and the other north, add 90° to the declination, and call the sum A.

Call the difference between the colatitude and coaltitude, B.

Let the half of the sum of A and B be called D, and the half of their difference be called C.

Then add together the four following logarithms, viz. the arithmetic complement of the logarithmic sine of the co-latitude, the arithmetic complement of the logarithmical sine of the coaltitude, the logarithmic sine of D, and the logarithmic sine of C.

Now take half the sum of those four logarithms,

logarithms, and that is the logarithmic sine of half the azimuth required.

For instance, in latitude $40^{\circ} 38'$ north, the sun's altitude in the afternoon was $20^{\circ} 46'$, and its declination $17^{\circ} 10'$ south; required the sun's azimuth for that time.

The declination +	90°	=	$107^{\circ} 10'$	= A
The coaltitude -	-	=	$69^{\circ} 14'$	
The colatitude -	-	=	$49^{\circ} 22'$	
The difference -	-	=	$19^{\circ} 52'$	= B
The half sum of A and B =			$63^{\circ} 31'$	= D
The half difference of A and B =			$43^{\circ} 39'$	= C
The arith. compl. of log. sine of colat. =			0,11982	
The arith. compl. of log. sine of coalt. =			0,02917	
The log. sine of D -	-	=	9,95185	
The log. sine of C -	-	=	9,83901	
Sum of those four logarithms -		=	19,93985	

the half of which is 9,96992, and this is the logarithmic sine of $38^{\circ} 55'$; the double of which, viz. $77^{\circ} 50'$, is the required sun's azimuth from the north point of the horizon.

PROBLEM V.

The true and magnetic amplitudes, or azimuths, of a celestial object, being given, to ascertain the variation of the compass for that time and place.

Let the amplitudes, as well as the azimuths, be all reckoned from the north point, which is done by subtracting it from 90° when the amplitude is northward of the east or west points, or by adding it to 90° when it is southward of the said points ; then either the magnetic amplitude is less or greater than the true amplitude.

When the magnetic amplitude is less than the true, and they are both on the same side of the north point, their difference is the variation towards the contrary side of the north ; but if they be on different sides of the north point, then their sum is the variation towards the same side with the true amplitude.

When the magnetic amplitude is greater than

than the true, and they are on the same side of the north point of the horizon, their difference shews the variation towards the same side; but if they be on different sides, then their sum is the variation towards the same side with the true amplitude. Thus, if the magnetic amplitude is 80° eastward of north, and the true amplitude is 82° towards the same side, then the variation is 2° west; and if the magnetic amplitude be 76° eastward of north, whilst the true is 5° westward of north, then the variation is 81° west.

What has been here said of the amplitudes, must be likewise understood of the azimuths, when the variation is to be estimated from them.

PROBLEM VI.

To observe the dipping of the magnetic needle.

For this operation nothing more is required than to place the dipping needle in the magnetic meridian, which must be as-

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certained

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certained by means of a good compass; but then the two instruments must be placed sufficiently far from each other. Sometimes the frame which holds the dipping needle is furnished with two sight vanes on an index, which moves horizontally, and through which a distant object, the bearing of which is accurately known, may be kept in view, in order to fix the dipping needle in the magnetic meridian; taking care to let the plain of the needle form the necessary angle with the index, or bearing of the distant object; which is shewn by the divided circle just under the index.

To compensate in some manner for the possible want of balance, the poles of the dipping needle are usually reversed, by means of magnetic bars; so that its two ends may be made to dip alternately, and a mean is taken of the two or more observations.

The greatest imperfection of the dipping needle is, that the magnetism of the earth acts upon it differently according to its different degrees of inclination, and also

†

according

according to its greater or less magnetic power. This property, which at first sight seems to be rather paradoxical, will be rendered evident by the following explanation.

Let A B, fig. 23. of plate II. be the dipping needle; the circle, E F, representing one end of its axis; the lower part F, of which rests upon the support C D; and E F is the line which passes through the centre of the needle, and divides it into two equal parts. It is evident, that before the needle has acquired any magnetism, if it be of a uniform figure, and the axis be truly cylindrical, and placed in its middle, the needle must remain in any situation it is placed, because the perpendicular raised from the point where the axis E F touches the support C D, passes always through the centre of the needle, dividing it into two equal and like parts; so that the needle is perfectly balanced in any degree of inclination. But it must be remarked, that though the needle be perfectly balanced, yet when it stands in an inclined situation, as shewn in fig. 24. the part of

it G A, which stands above the supporting point G, is longer than the part B G, which stands below it; and this difference increases as the inclination increases, because the axis of the needle is not a mathematical line, but a body of a certain diameter; so that when the needle stands perpendicular, the part of it which lies above the supporting plain exceeds the other part just by the diameter of the axis. Now, when the needle is inclined, as in fig. 24. suppose that two equal and like forces be applied to its extremities A and B, it is evident, that the force applied to the extremity A must have more power to move the needle than that applied to B, because G A is the longest lever of the two. This inequality of effect must increase with the inclination, and is greatest when the needle stands perpendicular.

The application of those forces takes place when the needle is made magnetic; for as the greatest attractive and repulsive powers between the magnetic poles of the earth, and the poles of the needle, act upon

upon the extremities A and B, the irregularity above mentioned must increase with the inclination, and with the degree of the needle's magnetic power.

Various methods have been proposed, in order to compensate for this irregularity; but none has yet been found to obviate it perfectly; and they generally introduce new imperfections.

CHAPTER VII.

Promiscuous Experiments.

EXPERIMENT I.

The magnetic paradox.

UPON the table A B, fig. 25, of plate II. place a piece of iron wire, not above a tenth of an inch long. Let the magnetic bar E F be held at about 4 or 5 inches above the table, with either

pole downwards, and in such a place as that the perpendicular let fall from it to the table may touch the table at G, *viz.* two or three inches distance from the iron wire; those distances, however, are subject to a good deal of variety, arising from the power of the magnet.

By the action of the magnet the iron wire will elevate one of its ends, as represented by C D, forming with the table an angle, which is larger the nearer the wire comes to the point G, where it stands quite erect.

In this situation, if you give gentle knocks to the table, the wire C D will gradually proceed towards G, every knock making it jump up and advance a little way. The reason of which a superficial observer would immediately attribute to the attraction between the magnet and the iron wire, which being not sufficiently strong to raise the wire from the table, has just power enough to draw it a little nearer to the point G, when the motion of the table lifts it up.

Thus far the experiment shews nothing extraordinary;

extraordinary; but if it be repeated with only this variation, *viz.* that the magnet, instead of being held above the table, be placed below it, *viz.* at H I; the event will be, that the wire, which will now make an obtuse angle towards G, as represented by K L, on knocking the table will gradually recede from the point G, shewing as if the magnet repelled it; which has given to this experiment the name of *magnetical paradox*; for, in fact, the magnet attracts the wire.

This phenomenon results from the directive property of the magnet acting at a greater distance than the attractive, as has been explained in Chapter VIII. of the first Part of this work.

In order to explain the immediate cause of this phenomenon, it must be considered, that the wire K L, fig. 26, plate II. being rendered magnetic by the action of the magnet H, is inclined to it according to the abovementioned laws of the dipping needle; but, on account of its weight, and because it is supported not in its centre, but by one end, namely K,

which stands upon the table, it does not incline so much as it ought to do if it were freely suspended by its centre, the end K now being a little higher than its proper situation. Let M N be the perpendicular, which passes through the centre of the wire. Now when, by the motion given to the table, the wire is made to jump; this, whilst remaining in the air, will take its proper inclination, as shewn by r Q, its centre remaining in the same perpendicular M N; for the directive power of the magnet H acts at a greater distance than its attraction. In this situation it is evident, that a perpendicular P O, let fall from the lower extremity r of the wire, touches the table in a point farther from G than the point K; and as the wire after the jump comes down to the table again with the proper inclination, viz. parallel to r Q, it follows, that now its lower end must touch the table at O: and thus every knock will force it to recede a little more from the point G, which lies just over the magnet H.

The same explanation applied to the first part

part of the experiment, will shew that the wire must in that case, *viz.* when the magnet is held above the table, approach continually the point G.

This experiment may be diversified by using iron filings instead of the iron wire; for, in the first case, the filings dispersed over the table will be gradually collected about the point G; and in the latter case, the filings placed about the point G will be gradually forced to recede from that point.

EXPERIMENT II.

To arm natural and artificial magnets.

When a piece of natural magnet is required to be armed, the first operation is to find out its poles; then let the magnet be properly shaped, *viz.* either in the form of a terrella, or in the more usual one of a parallelopipedon, in which latter case care must be had to let the poles fall about the middle of two opposite surfaces, in which

which direction the magnet ought to have the greatest length possible; it having been often observed, that a natural magnet is weakened in power much more by cutting off a part of its length, in the direction of the poles, *viz.* so as to make the magnetic axis shorter, than in any other direction.

After having shaped the magnet properly, let two plates of soft iron be made, equal in breadth to those surfaces where the poles stand, and to project a little way on one side of the stone, as shewn by fig. I. plate I. Those projections D, D, must be much narrower than the breadth of the plates. For magnets smaller than one ounce, the lower surfaces of the projections to which the iron F is to be applied, need not be larger than about one tenth of an inch; and from a quarter to half an inch is sufficient for larger magnets.

The thickness of the plates C D, C D, must be proportioned to the power of the magnet; there being a certain size, which is the properst for any magnet, a larger or smaller thickness than which being not so advantageous. This thickness cannot be

be easily determined without actual trial; hence the best way is to make them very thick at first; then filing a little off, and examining the power of the magnet alternately; for the power increases gradually till a certain degree, at which limit the filing ought to be discontinued.

It is indifferent whether the armature be kept on by tying, or by a box, whether of metal or of wood; but as the box is the most permanent, this ought to be preferred; and it may be made of any metal excepting iron or steel.

When the magnet is spherical, the armature, or pieces of iron, must be adapted to that surface, and each to cover about a quarter of it.

What has been here said about the natural magnet, is equally applicable to the artificial ones; so that many magnetic bars may be joined together, and may be armed so as to form a very powerful *compound magnet*.

The armature rather strengthens the power of the magnet, for the same reason for which a piece of iron, affixed to a magnet, tends to render it more powerful.

If the artificial magnets be made in the shape of a horse-shoe, or of a semicircle, then there is no need of the armature, it being sufficient to join them together, either by rivetting or by a box ; and, indeed, even with straight bars the compound magnet may be made without the armature ; but then, as the two magnetic poles cannot act in the same plain, it is proper to have two of those compound magnets, for the purpose of giving, more conveniently, magnetism to other bodies*.

* By this means the late Dr. Gowin Knight constructed two very powerful artificial magnets, or magazines of magnetic bars, which are now in the repository of the Royal Society. Each of those magazines consists of 240 bars, disposed in four lengths, so as to form a parallelopipedon, every length containing 64 bars. All those bars are kept together by means of iron braces, and the whole is suspended upon pivots and a proper wooden pedestal or carriage, so as to be easily placed in any required position.—For a farther description of those magnetic magazines, see the Phil. Trans. vol. LXVI. p. 591.

EXPERIMENT III.

To communicate magnetism to a needle by means of electricity.

Place a small sewing needle, or a piece of steel wire, on a table, and connect one extremity of it with the outside of a charged electric jar or battery *, by means of a wire. Let the other extremity of the needle be connected, by means of another wire, to one branch of the usual discharging rod; then bring the other knob of the discharging rod in contact with the knob of the jar or battery, so as to make the discharge, which passing through the needle will render it magnetic, or reverse its poles, &c. according to the circumstances enumerated in the first Part of this work.

* This jar or battery ought, at least, to have two square feet of coated surface, but this depends on the size of the needle.—See the writers on electricity for an explanation of the electrical instruments.

EXPERIMENT IV.

To shew that magnetism requires a certain time to penetrate through a piece of iron.

Place a bulky piece of iron, for instance, a short piece of about 40 or 50 lb. weight, sideway of one of the poles of a magnetic needle, so as to draw the needle a little out of its natural direction. Then apply one pole of a strong magnet to the farthest end of the iron, and you will find that there requires some time, *viz.* some seconds, before the needle be affected by it. This time is different according to the different size of the piece of iron, and of the power of the magnet.

EXPERIMENT V.

To imitate the natural magnets.

Take some martial æthiops, or, which is more easily procured, reduce into very fine

fine powder the scales of iron, which fall from red-hot iron when hammered, and which are found abundantly in smiths shops. Mix this powder with drying linseed-oil, so as to form it into a very stiff paste, and shape it in a mould so as to give it any form you require, whether of a terrella, a human head, or any other. This done, place it in a warm place for some weeks, and it will dry so as to become very hard. Then render it magnetic, by the proper application of powerful magnets, and it will acquire a considerable power*.

EXPERIMENT

* The late Dr. John Fothergill, giving an account of Dr. Knight's magnetical machine, in the 66th vol. of the Phil. Trans. p. 595, mentions the following remarkable circumstance; which, however, I think must have been partly occasioned by some mistake or misinformation. "I do not know," says he, "that the Doctor left behind him any description of a composition he had made to form artificial loadstones. I have seen in his possession, and many other of his friends have likewise seen, such a composition; which retained the magnetic virtue in a manner much more fixed, than either any real loadstone, or any magnetic bar, however well tempered.

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EXPERIMENT VI.

To weaken, or to destroy the magnetism of a wire, by bending.

Communicate the magnetic power to an iron wire, or soft steel wire, of about four or five inches in length, and about $\frac{1}{3}$.

" In the natural ones, he could change the poles in an instant, so likewise in the hardest bars ; but in the composition the poles were immovable. He had several small pieces of this composition, which had strong magnetic powers. The largest was about half an inch in breadth, very little longer than broad, and near a quarter of an inch thick. It was not armed, but the ends were powerfully magnetic ; nor could the poles be altered, though it was placed between two of his largest bars, and they were very strongly impregnated. The mass was not very heavy, and had much the appearance of a piece of black lead, though not quite so shining. I believe he never divulged the composition ; but, I think, he once told me, the basis of it was filings of iron, reduced by long-continued attrition with water to a perfectly impalpable state, and then incorporated with some pliant matter, to give it due consistency."

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of an inch in diameter ; then roll it round a small stick, so as to make four or five revolutions round the stick ; after which, on straightening the wire again, its magnetism will be generally found to be quite destroyed by the bending, or considerably weakened.

The effect is the same with shorter or longer wires ; for if they make one revolution round the stick, the effect will take place, which is evidently owing to the stress or derangement of the particles of the wire, as is rendered more evident by the following observation ; *viz.* that if the wire be of such springy nature as to recover its straight situation if left to itself after coiling it round the stick, then its magnetism is either not at all, or little diminished ; so that in order to produce the above-mentioned effect, a straining of the parts of the wire is absolutely necessary.

When only the middle of the wire is bent, and its extremities remain straight, then the magnetism is seldom destroyed, or even diminished.

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If a piece of magnetic wire be cleft or split lengthways, the parts will have sometimes contrary, and sometimes the same poles as they had when in one piece. When one part is much thinner than the other, then this slender part will generally have its poles reversed.

P A R T IV.

NEW MAGNETICAL EXPERIMENTS.

HAVING in the preceding pages taken notice of whatever had been ascertained with respect to magnetism, and of the experiments which seemed necessary to prove those magnetical laws, I shall now briefly relate those experiments of mine relative to magnetism, which were attended with some apparently useful event, arranging in each chapter those particulars which are naturally more connected together, without paying any regard to the time in which the experiments were made, and also without mentioning a variety of unsuccessful trials, or of projects not yet verified by actual experience.

CHAPTER I.

Description of a new sort of suspension for a magnetic needle, principally intended for ascertaining small degrees of magnetic attraction; and some remarks on the use of quicksilver.

PREVIOUS to the narration of the experiments on the magnetism of brass and of iron in its different states, which are to be related in this Part, I shall describe the magnetic needle generally used for those experiments, which is suspended in a particular manner; it being a very simple, and at the same time a very nimble sort of suspension.

Experience having shewn, that large magnetic needles are not proper for experiments wherein a very small degree of magnetism must be ascertained, and the free motion of the usual small needles being proportionably more obstructed by the nature of their suspension, even when furnished with agate caps, I endeavoured

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to contrive a sort of suspension which might answer the purpose better than the needles suspended in the usual manner; and, after several attempts, at last I constructed a chain of horse-hair, consisting of five or six links, to which the needle was suspended. Each link is about three quarters of an inch in diameter; and the extremities of each piece of hair, which is formed in a ring, are joined by a knot, and secured by a little sealing-wax. The link on one end of this chain is suspended on a pin in a proper frame, or on any support that may be at hand; and to the link of the other extremity, which lies lowermost, a piece of fine silver wire is hooked. This wire is about an inch and a half long, and its lower extremity is fastened round a small and cylindrical piece of cork, through which a common sewing needle, made magnetic, is thrust horizontally. Thus the magnetic needle is kept suspended by a hair-chain, the links of which, on account of the smoothness and lightness of the hair, move very freely in each other, and allow the needle more

than a whole revolution round its centre, with so small a degree of friction as may be considered next to nothing. By comparing this needle with others of the best sort now in use, I find it much more sensible; for when bodies which have an exceedingly small magnetic power are tried, this needle will be frequently attracted by them when the others are not sensibly affected.

In order to try farther the delicacy of such suspension, I placed a piece of looking-glass under the needle, and nearly horizontal; so that the image of the needle was seen in it. Now, as a fine line had been previously marked on the glass, things were so disposed as that the image of the needle might coincide with the line marked on the glass, the eye of the observer being placed in a proper point of view; afterwards, by shaking the needle either very gently or very quickly, I repeatedly endeavoured to place it out of the magnetic meridian; but every endeavour proved ineffectual, for the needle

dle constantly settled in the same direction, without any sensible deviation.

With a needle thus suspended a variation compass might be very easily constructed, and it would, perhaps, be more accurate than those commonly in use. For this purpose the needle ought to be about three inches long, and the piece of looking-glass ought to be fixed upon the index of an Hadley's sextant, which must be placed horizontally under the needle, with its edge or fiducial line in the meridian of the place, in order to observe the daily variation of the needle. I have made only a rough model of such a variation compass, and it seemed to answer very well.

This construction appears to have the following advantages over the common sort : 1st. The needle being cylindrical, and without a hole through the middle, would be less subject to have more than two poles. 2dly. The needle being slender, its poles would stand more exactly in its axis, which with the common flat needles is seldom the case. 3dly. It will appear, by a little considera-

tion, that in this construction there is no need of the needle's centre of motion keeping always in the same invariable point, which renders the construction both very easy and very accurate. And, lastly, as the sextant may be placed at a considerable distance below the needle, and the rest of the frame may be made of any size, there would be no necessity of placing any brass or other metal so near the needle as might affect it in case this metal had any magnetism, which generally happens with brass.

In order to examine the magnetism of divers substances, besides the above described needle, I used to place the substance to be examined, upon water, sometimes resting it upon flat pieces of cork or upon quicksilver, which last method, though incomparably nicer than the others, is however very troublesome on account of the following circumstances, for which reason I generally contented myself with using only the needle suspended by a hair chain.

In the course of the experiments in which

which quicksilver was used, I observed a remarkable phenomenon, respecting the surface of that metal; it is, that though substances will float upon it wonderfully nimble when it is first poured out into the open vessel, yet a short time after, *viz.* after having remained for an hour or two, and often a shorter time, in the open vessel, a piece of brass or other substance will by no means float upon it with equal facility; so that some substances, which after first pouring out the quicksilver into the open vessel were evidently attracted by the magnet, an hour after were not in the least moved by it.

The only effectual method which would render the quicksilver again fit for the purpose, was to pass it through a funnel of paper, as described in page 180; which operation I have been obliged sometimes to repeat four or five times in about two hours time.

There seems to be formed a kind of crust upon the surface of the mercury thus exposed, which, though invisible by mere inspection, may be perceived by moving

ing the floating substance upon it ; for soon after, having passed the quicksilver through the paper funnel, the floating substance, when moved, seems to proceed by itself ; whereas some time after the same substance, when moved, seems to communicate that motion to the adjacent quicksilver, and to drag it along with itself, somewhat like what happens when one moves something that floats upon the surface of a liquor which begins to coagulate.

The formation of this crust I attributed to the imperfect metals, which, though in small quantities, are generally amalgamated with the common sort of quicksilver ; for that amalgamation tending to dephlogisticate those metals, the half calcined part floats at the top ; and it is most likely that the said dephlogistication goes on very ~~strengthens~~ quick in the open air. What ~~invalidates~~ strengthens this supposition is, that the purer the quicksilver is, the least is the crust formed, or opposition made to the floating substances ; however, I have observed it in some measure, even in the purest quicksilver, and am inclined to think, that it must be partly

partly owing to some moisture or invisible dust, which adheres to the surface of the quicksilver that is exposed to the atmosphere.

CHAPTER II.

Examination of the magnetical properties of brass.

A FEW years ago, being intent on making some magnetic experiments, in which brass was concerned, I used to examine first whether the pieces of brass had any magnetism or not, and rejected those pieces which had an evident degree of that power. In the course of those experiments I remember to have observed, that those pieces of brass which had been hammered were generally magnetic, and much more so than others; in consequence of which I made no use of hammered brass in those experiments. But

about a year and a half ago, having ordered a theodolite at a philosophical instrument shop, I particularly enjoined the workmen to try the brass, both soft and hammered, before they worked it, and to make no use of that which had an evident degree of magnetic power. They found, that hammered brass, even such as before the hammering had no magnetism, could afterwards disturb the magnetic needle very sensibly. These observations induced me to make the following experiments.

Experiment I. An oblong piece of brass, weighing somewhat less than half an ounce, being examined, by presenting every part of its surface to the suspended needle, shewed no sign of magnetism whatever. It was then hammered for about two minutes; the consequence of which was, that it became magnetic so far as to attract either end of the needle from about a quarter of an inch distance. This same piece of brass being now put into the fire so as to become red-hot, by which means it was softened, and when cold being presented to the suspended needle, its magnetism was

found to be entirely gone. Hammering made it again magnetic ; softening by fire took the magnetism away a second time : and thus the magnetism was repeatedly given it by hammering, and was destroyed by softening ; sometimes shewing to have acquired a sensible degree of that power even after two or three strokes of the hammer.

Experiment II. The result of the first experiment would naturally induce one to suspect, that the hammer and anvil might have imparted some small quantity of steel to the brass, which rendered it magnetic ; and that this magnetism was destroyed in softening the brass, insomuch as the fire calcined the small quantity of steel that had adhered to it. In consequence of which consideration, I took other pieces of brass besides that used before, and hammered them between card-paper, changing the pieces of paper as often as was necessary, since they were easily broken by the hammer ; but the pieces of brass became constantly magnetic by the hammering, and their magnetism was destroyed by fire.

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In this experiment I generally gave to the brass not above thirty strokes with the hammer.

Experiment III. Still suspecting that the hammer and the anvil might have imparted some small quantity of iron to the brass, because the pieces of card-paper sometimes were broken by the first or second stroke, in which case either the hammer or the anvil touched the brass, I hardened a piece of brass by beating it between two large flints; *viz.* using one for the hammer, and the other for the anvil. The piece of brass became magnetic, though in this case it seemed to have acquired not so much power as when it had been hardened with the hammer; but it must be observed, that the flints being rough and irregular, the piece of brass could not be hardened by them so easily, or so equally, as by the other method.

The flints, being examined both before and after the experiment, were found to have not the least degree of magnetism.

Experiment IV. A piece of brass, which by hammering had been rendered so strongly magnetic

magnetic as to attract either pole of the needle from about a quarter of an inch distance, was put into a crucible, together with a considerable quantity of charcoal dust, which surrounded it every where. The crucible was covered with clay, and being placed into the fire, was kept red-hot for about ten minutes. After cooling, the piece of brass was taken out of the crucible, and being examined, was found to have entirely lost its magnetism. The object of this experiment was to ascertain whether the loss of magnetism, in a piece of brass that was softened, was owing to the calcination of the ferruginous particles, which, notwithstanding the preceding experiment, might still be suspected to be imparted to it; because in this way of softening the brass, the ferruginous particles being surrounded with charcoal dust, could not have been calcined; hence the brass ought not to have lost its magnetism, which however was not the result of the experiment.

Experiment V. One of those pieces of brass, which had been used for the foregoing

going experiments, and which had been deprived of magnetism by fire, was hammered between two large and pretty thick pieces of copper, which had not the least magnetism ; and after a few strokes of the hammer, it became sensibly magnetic.

Experiment VI. In order to examine the difference of this property in brass of various kinds, I have tried a great many pieces of English as well as foreign brass ; some of which was very old, and so fine and uniform, that an eminent watchmaker of my acquaintance used it for the very best sort of watch-work. But I find that they mostly have the property of becoming magnetic by hammering, and of losing that power when softened. There are, however, some pieces which acquire no magnetism by the hammering, though they are rendered equally hard by it as those which acquire the magnetism. By attentively examining them, I have not yet been able to distinguish, without a trial, which pieces are capable of acquiring magnetism, and which not ; the colour, apparent texture,

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and degree of ductility, seeming to afford no sure indication.

Experiment VII. The preceding experiments seem to render evident the existence of magnetism, or of the power of attracting and being attracted by the magnet, independent of iron; yet an objection may be made against this consequence, which is, that the brass which becomes magnetic by hammering, and loses that power by softening, might contain a small quantity of iron, to which that magnetism was owing; and that this iron, or martial earth, dispersed through the substance of the brass, might become phlogisticated by the action of the hammering; insomuch as the brass being forced into a smaller space, might perhaps give some of its phlogiston to the martial earth, and thus render it sensibly magnetic; and, on the contrary, the action of the fire in softening, might remove that phlogiston from the martial earth, and give it again to the brass; hence the former, remaining quite dephlogisticated, would no longer shew any signs of magnetism. The consideration that iron

may be dephlogisticated or calcined more easily than brass, gave an apparent weight to the supposition; but the following experiments seem to expel every doubt.

Having chosen a piece of brass, which would acquire no magnetism by hammering, I placed it upon an anvil, together with a considerable quantity of *crocus martis*, which crocus had no action on the magnetic needle; then began hammering the brass, and turning it frequently, in order to let part of the crocus adhere to it; and, in fact, the crocus had, in several places, been fastened so well into the brass, that hard wiping with a woollen cloth would not rub it off. The brass appeared red in those places; but, after having been hammered for a long time, it acquired no magnetism whatever. The hardening, therefore, could not render the iron calx so far phlogisticated as to affect the magnetic needle.

Experiment VIII. In order to diversify the preceding experiment, I drilled a hole, about one-eighth of an inch long, and little more than one-fiftieth of an inch in diameter,

eter, into a piece of brass that was not rendered magnetic by hammering, and filled it with *crocus martis*; then I hammered the piece of brass, thus inclosing the calx of iron, and afterwards presented it to the suspended magnetic needle; but there was not the least sign of attraction: the martial earth, therefore, had not acquired any phlogiston from the brass by the action of hammering.

Experiment IX. The same piece of brass, containing a small quantity of calx of iron, was put into the fire, and was made quite red-hot, in which state it remained for about three minutes. Then, after cooling, it was presented to the magnetic needle, and this was attracted by the brass only in that place wherein the calx of iron was contained. The action, therefore, of the fire had rendered the martial earth so far phlogisticated as to attract the magnetic needle; hence, if the magnetism of brass were owing to any ferruginous matter contained in it, a piece of brass ought to become magnetic when softened;

which is contrary to the foregoing observations.

Experiment X. A hole, similar to that mentioned in the VIIth Experiment, was drilled into a piece of brass that would not become magnetic by hammering, and into it was put some black calx of iron, which was so far phlogisticated as to be attractable by the magnet, and the hole was closed by a few strokes of the hammer. In consequence of this, the piece of brass, when presented to the suspended needle, would attract it only about that place where the magnetic calx was contained. This attraction was very weak. The piece of brass thus prepared, was then put into the fire, and was kept for about six minutes in a heat very little short of that necessary to melt brass, and after cooling I presented it to the needle, expecting that the fire might have dephlogisticated the calx of iron so far as not to let it act any longer upon the needle; but the attraction appeared to be of the same degree it was before the heating.

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It seems, therefore, clear, that the magnetism acquired by brass, when hammered, is not owing to iron contained in it; and consequently, that *magnetism, or the power of being attracted by, and attracting, the magnet, may exist independent of iron.*

Experiment XI. A small quantity of iron was mixed, by means of the blow-pipe, with about four times its weight of such brass as would not become magnetic by hammering. The whole globule weighed about two grains, and it attracted the magnetic needle very powerfully. I then melted this globule of brass and iron with about fifty grains of the same sort of brass as had been used before. After cooling, the whole lump of brass appeared to have very little power upon the magnetic needle, every part of its surface attracting one end of the suspended needle, so as to let it just adhere to it when the air was not at all disturbed. But this weak and hardly perceptible degree of magnetism was not increased by hammering, nor annihilated by softening.

In this experiment I thought to have

fused and incorporated together brass and iron ; but some subsequent trials gave reason to believe, that the iron is concealed in some part or other of the melted brass, rather than equably diffused through the substance of the latter ; and the principal reason for this supposition is, that when those pieces of mixed metal are tried upon the quicksilver, some points in their surfaces are generally attracted by the magnet in preference to others.

It must here also be observed, that having repeated most of the preceding experiments, by examining the pieces of brass upon quicksilver, and presenting the magnet to them, instead of presenting them to the needle, the result was, that very seldom a piece of brass occurred, which was not affected by the magnet ; and even when they were not affected by it, their indifference was not very clear and decisive ; and indeed there are very few substances in nature, which, when examined by this means, are not, in some degree, attracted by the magnet ; so general is the dispersion of iron, or such is the tendency

tendency which most bodies have towards the magnet.

Such brass which in the former experiments appeared to have no magnetism naturally; nor to acquire any by hammering, was now found to be mostly magnetic, though in so small a degree as to be discoverable only when floating upon quicksilver; but those pieces of brass which naturally had not any degree of magnetism sufficient to affect the needle, nor acquired any by hammering, but yet shewed some tendency towards the magnet when floating upon quicksilver, never, or very seldom, had that tendency increased by hammering.

It is now proper to collect, under one point of view, all the observations which have been deduced from the foregoing and other experiments relating to the magnetic properties of brass. It appears, therefore,

1st. That most brass becomes magnetic by hammering, and loses the magnetism by annealing or softening in the fire, or at least its magnetism is so far weakened by

it as afterwards to be only discoverable when set to float on quicksilver.

2dly. That the acquired magnetism is not owing to particles of iron or steel imparted to the brass by the tools employed, or naturally mixed with the brass.

3dly. Those pieces of brass which have that property, retain it without any diminution after a great number of repeated trials, *viz.* after having been repeatedly hardened and softened. But I have not found any means of giving that property to such brass as had it not naturally.

4thly. A large piece of brass has generally a magnetic power somewhat stronger than a smaller piece; and the flat surface of the piece draws the needle more forcibly than the edge or corner of it.

5thly. If only one end of a large piece of brass be hammered, then that end alone will disturb the magnetic needle, and not the rest.

6thly. The magnetic power which brass acquires by hammering has a certain limit, beyond which it cannot be increased by farther

farther hammering. This limit is various in pieces of brass of different thickness and likewise of different quality.

7thly. Though there are some pieces of brass which have not the property of being rendered magnetic by hammering, yet all the pieces of magnetic brass, that I have tried, lose their magnetism, so as no longer to affect the needle, by being made red-hot; excepting indeed when some pieces of iron are concealed in them, which sometimes occurs; but in this case, the piece of brass, after having been made red-hot and cooled, will attract the needle more forcibly with one part of its surface than with the rest of it; and hence, by turning the piece of brass about, and presenting every part of it successively to the suspended magnetic needle, one may easily discover in what part of it the iron is lodged.

8thly. In the course of my experiments on the magnetism of brass, I have twice observed the following remarkable circumstance:—A piece of brass, which had the property of becoming magnetic by hammering, and of losing the magnetism by softening,

softening, having been left in the fire till it was partially melted, I found, upon trial, that it had lost the property of becoming magnetic by hammering; but having been afterwards fairly fused in a crucible, it thereby acquired the property it had originally, *viz.* that of becoming magnetic by hammering.

9thly. I have likewise often observed, that a long continuance in a fire so strong as to be little short of melting-hot, generally diminishes, and sometimes quite destroys, the property of becoming magnetic in brass. At the same time, the texture of the metal is considerably altered, becoming what some workmen call *rotten*. From this it appears, that the property of becoming magnetic in brass by hammering, is rather owing to some particular configuration of its parts, than to the admixture of any iron; which is confirmed still farther by observing, that Dutch plate-brass (which is made not by melting the copper, but by keeping it in a strong degree of heat whilst surrounded by *lapis calaminaris*) also possesses that property;

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at least, all the pieces of it, which I have tried, have that property.

From these observations it follows, that when brass is to be used for the construction of instruments wherein a magnetic needle is concerned, as dipping needles, variation compasses, &c. the brass should be either left quite soft, or it should be chosen of such a sort as will not be made magnetic by hammering; which sort, however, does not occur very frequently.

CHAPTER III.

Examination of the magnetic properties of some other metallic substances.

THE result of the experiments on brass induced me to examine other metallic substances, and especially its components, *viz.* copper and zinc: though the result of the experiments has not been very remarkable, excepting with platina, which

which metal has properties in great measure analogous to those of brass.

Having examined various pieces of copper, by means of the suspended magnetic needle, and having never found them magnetical, except only sometimes in such places which had been filed, and where some particles of steel might have been left by the file, I next proceeded to hammer some pieces of it, not only in the usual way, but likewise between flints: the result, however, was very dubious; for though, in general, they had no effect whatever on the needle, yet sometimes I thought the needle was really attracted by some pieces of hammered copper; but then this attractive power was so exceedingly small as not to be depended upon.

Zinc, either not hammered, or hammered as far as could be done without breaking it, shewed no signs of attraction whatever, when presented to the magnetic needle. Neither had a mixture of zinc and tin any action upon the needle.

A piece of broken reflector of a telescope, which consisted of tin and copper; a mixture

a mixture of tin, zinc, and a little copper; a piece of silver, both soft and hammered; a piece of pure gold, both soft and hammered; a mixture of gold and silver, both hard and soft; and another mixture of a great deal of silver, a little copper, and a less quantity of gold, either before or after hammering, had not the least action on the magnetic needle.

Nickel is a metallic substance, which has been suspected to possess some degree of attraction towards the magnet, independent of iron; and this suspicion has been founded upon observing, that nickel retained its magnetism after having been repeatedly purified*. There are, however, persons who have denied the magnetism of purified nickel; and I have seen some pieces of it which did not, in the least, affect the magnetic needle. It is probable that those pieces were not pure nickel, and perhaps some cobalt was contained in them; but I see no reason why the nickel, when alloyed with a little co-

* See Kirwan's Mineralogy, p. 342 and 367.

balt,

balt, should shew no attraction towards the magnet, if that property did really belong essentially to it.

Platina was the metal I last examined, and the experiments made with it seem to deserve particular attention.

Experiment I. A large piece of platina, which after having been precipitated from its solution in *aqua regia*, had been fused, or rather concreted together, being presented to the suspended magnetic needle, shewed not the least sign of magnetism. It was then hammered; but after the third or fourth stroke of the hammer it broke into many pieces, several of which being tried, shewed no attraction, nor could any of the finest particles be attracted by the magnet presented very nearly over them. The broken surface of this piece of platina was full of cavities, some of which were large, and others just discernible; and altogether the metal seemed to have undergone an imperfect fusion.

Experiment II. The grains of native platina were examined next, by putting a magnet just over them; but the magnet attracted

attracted not above ten or twenty particles out of about half an ounce of platina: and those which were attracted had little or no shining metallic appearance, like the rest, and were exceedingly small.

Experiment III. Having picked out several of the largest grains of platina, I presented the magnet to them; but they were not in the least attracted by it. One of those grains was then hammered; by which means, after about eight or ten strokes, it was spread into a plate, about a tenth of an inch in diameter, and nearly circular; afterwards, the magnet being presented to it, the former attracted it from the distance of about one-twentieth of an inch. The other grains being all hammered one after the other, were rendered by it so far magnetic as to be attracted by the magnet, and to disturb the magnetic needle when presented to it. But there were some amongst them which acquired no magnetism at all, though they had been purposely hammered much longer than the others.

As far as I could observe, those pieces

which would not acquire any magnetism by hammering, had not a very shining appearance before the hammering, though afterwards they could not be distinguished from the others by their appearance; and they seemed not to spread under the hammer so easily as the others.

In general, three or four strokes are sufficient to render a grain of platina evidently attractive by the magnet; but about ten strokes give it the full power it is susceptible of.

Experiment IV. Those grains of platina, which in the preceding Experiment the hammering had rendered capable of being attracted by the magnet, being put upon a charcoal, were made red-hot by means of a blow-pipe; and afterwards, being presented to the magnet, and likewise to the suspended needle, they shewed not the least sign of attraction. Heat, therefore, deprives them, as well as brads, of the property acquired by hammering. A second hammering rendered them again attractive, though not so quickly, nor in so great a degree as it had done the first time. However,

ever, it must be observed, that the pieces of platina having been rendered flat and thin by the first hammering, could not be so easily struck, nor spread much more, by the second.

Experiment V. When the grains of platina were examined by the magnet whilst floating on the surface of quicksilver, almost every one of them was attracted in a small degree; and this attraction was generally somewhat increased by the hammering, even in those which had it never increased so far as to attract the magnetic needle.

If it be true, as those experiments seem to prove beyond a doubt, that the power of being attracted by the magnet may exist, or may belong to other substances, independent of iron, it must follow, that the attraction of a few particles of any unknown substance by the magnet is not a sure sign of the presence of iron. Hence those substances, which hitherto have been considered as containing ferruginous particles, for no other reason but because the magnet attracted them in a small degree,

must be considered as dubious; and the conclusion of the existence of iron ought not to be admitted, except when those particles, which have been separated by the magnet, appear to be iron by some other trial; for though it be true, that iron is always attracted by the magnet, yet it does not hence follow, that whatever is attracted by the magnet must be iron.

CHAPTER IV.

Experiments and observations relating to the attraction between ferruginous substances and the magnet, in their different states of existence.

IT is a proposition well established in magnetics, that soft iron, or soft steel, acquires magnetism very easily, and loses it with equal facility; but that hard steel acquires that power with difficulty, and afterwards

afterwards retains it obstinately. From the consideration of those properties, I was led to imagine, that if a piece of steel, whilst red-hot, were placed between magnetic bars, and whilst standing in that situation cold water were to be suddenly poured upon it, so as to harden it, there might, perhaps, be obtained an artificial magnet, much more powerful than what can be produced by the ordinary way; because the magnetic bars, employed for such purpose, would communicate a great degree of magnetic power to the steel, when red-hot, and consequently soft, which power would be fixed upon the steel by the hardening.

In order to put this project to the trial, six magnetic bars were so disposed, in an oblong earthen vessel, as that the north poles of three of them might be opposite the south poles of the three others, forming two parcels of bars, lying in the same direction, and about three inches asunder, which was nearly the length of the steel bar which was intended to be rendered magnetic. Things being thus disposed,

the steel bar was made quite red-hot, and in that state was placed between the magnetic bars; after which, cold water was immediately poured upon it, which rendered it so hard as not to admit being filed: its magnetism was found to be considerably strong, but by no means extraordinary. From repeated trials with steel bars of different sizes, and by using a greater or less number of magnetic bars, I found, that short steel bars acquire a proportionably greater degree of magnetism, by this method, than those which were longer; that the magnetism in the longer bars is not proportionably as strong, principally because the artificial magnets, being placed at their extremities, have very little power on those parts of the pieces of steel which are nearer its centre; and, lastly, that when, in order to remedy the just-mentioned inconvenience, more magnets are placed nearer the middle of the steel bar, then this piece of steel generally acquires many successive magnetic poles.

Upon the whole, it seems that though this method alone be not sufficient to

communicate to steel bars an extraordinary degree of magnetism, yet it may be of great use in constructing large artificial magnets; for if those bars, instead of being hardened in the usual way, by plunging them, when red-hot, in water, be hardened whilst standing between powerful magnets, they will thereby acquire a considerable degree of magnetic power, without any additional trouble to the workman. They may then be polished, after which they may be rendered more strongly magnetic by the usual method of touching them with other magnetic bars; whereas it is a very laborious operation to render magnetic large bars of hardened steel from the very beginning, *viz.* when they have none of that power.

In the course of performing those trials, I frequently observed, that the pieces of steel, whilst they were red-hot, seemed not to be attracted by the magnets; so that the least shock, and even the pouring of the water, could remove them from the proper situation, which rather surprised me; because it has been asserted by some

authors, that the magnet attracts red-hot iron as well as cold. Kircher especially says, that he tried the experiment*, and found that the piece of iron, heated so as to be hardly discernible from a burning coal, was attracted by the magnet as easily as when cold ; and he even assigns a reason why the power of a magnet is destroyed by a great degree of heat ; whereas the red heating of the iron will not prevent its being attracted by the magnet. The reason he gives is, that the fire corrupts and calcines the magnet, but purifies the iron. The following experiments were made in order to ascertain this matter :

I kept a piece of steel in the fire till it was quite red-hot, and in that state presented the magnet to it, so as to touch it repeatedly in various places ; but no sign of attraction could be perceived before the redness disappeared. I mean, however, such redness as may be evidently seen in the clear day-light ; for, as was shewn by other experiments, when the magnet be-

* *De Magnete*, lib. I. p. II, theorem XXXI.

gins to attract the heated iron, the redness of the latter can still be seen in the dark.

Having repeated the experiment with different pieces of iron, and of steel, the result was constantly the same, *viz.* whilst the iron or steel remained quite red-hot, or white-hot, the magnet did not attract it; but the attraction began when the degree of redness, which is clearly perceptible in the day-light, began to disappear; and it was as strong as ever when the iron was cooled a little more than when the redness quite disappeared in the dark. In regard to this limit, or maximum of attraction, I think I have observed, as well as the nature of the experiment would permit, a difference between steel and iron; which is, that in the steel the maximum of attraction follows the disappearance of the red heat sooner than in iron.

This experiment is subject to two sources of mistake, which perhaps misled Father Kircher, and which it is necessary to mention, for the sake of others who wish to repeat it. The first is, that when a piece of iron, of no great extent,

is red-hot, or even white-hot, in one place, and below a red heat in other parts, the magnet will frequently attract it, though the red-hot side be presented to it. The second cause of mistake is, that when a small piece of iron or steel, as a common sewing needle, is made red-hot, and is then presented to the magnet, if the magnet touch it, that contact cools it instantly below the necessary degree of heat, and of course the attraction takes place. It is owing to this last cause that I have not yet been able to ascertain, whether the attraction between the magnet and the iron be quite annihilated, or only diminished to a great degree, by rendering the iron red or white hot; so that I can only say with certainty, that a magnet will not attract a certain piece of iron red-hot or white hot; whereas it will attract another piece of iron, at least fifty times bigger, if it be cold, or below a red heat.

To try this experiment in a different and more convincing manner, I heated a large iron nail till it was white-hot, and

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in that state placed it upon an earthen support, near one pole of the magnetic needle, so as to lie not in the same direction, but on one side of it. Then, looking attentively on the graduated circle of the compass, I observed, that the needle was not in the least moved from its natural situation, whilst the nail remained red-hot; but as soon as the redness began to disappear, the needle advanced towards the nail, and a few seconds after the needle pointed directly towards it.

I tried whether, in this experiment, any difference was occasioned by the magnet's being natural or artificial; but, as it might be expected, there was none.

In pursuance of those magnetic experiments wherein heat is concerned, I tried the effects which took place when the magnet was heated; but, as the diminution of its power by heating, and an increase of it by cooling, were observed and described by the late Mr. Canton*, I shall only add a circumstance, which may perhaps be new. It is, that an artificial magnet, after having had its power diminished

* Phil. Trans. Vol. LI.

by heating, does not recover it intirely again by cooling ; having constantly found, that the magnets which had been heated, after cooling would never hold as great a weight of iron as they did before.. The heat to which those magnets were exposed never exceeded that of boiling water. This was rendered more evident by the following experiment.

A magnetic bar was placed, in an earthen vessel, at some distance from the south pole of the needle of a very good compass ; by the action of which magnet that end of the needle was drawn several degrees from the magnetic meridian, or from the direction in which it stood before. In this situation of the apparatus, boiling water was poured into the vessel wherein the magnet stood, in consequence of which the needle went back two degrees and a half. Some time after, when the water was quite cold, the needle was found nearer to the magnet, but not so near as it stood before the hot water was poured into the vessel.

Next to the effects of heat, I was desirous

fious of trying what could be effected by decomposing the iron ; and for this purpose an earthen vessel, containing about two ounces of iron filings, was placed near the south end of the needle of the compass, by which the needle was drawn a little out of its natural direction. Having marked where the needle now stood, some water first, and then some vitriolic acid, were poured upon the filings, which occasioned a brisk effervescence, and a copious production of inflammable air ; but soon after the beginning of the effervescence, I was surprised to observe, that the needle came nearer to the vessel, shewing that the attraction between the needle and the filings had been increased by the action of the vitriolic acid upon the latter, which is contrary to what could have been expected ; for if we consider that the power of a magnet is diminished by heat, and that red-hot iron has either no attraction at all, or an exceedingly small degree of it, towards the magnet, we might have concluded, that the action of the vitriolic

vitriolic acid upon iron would immediately diminish its attraction, besides the other strong reason, arising from the dephlogistification of the iron occasioned by the effervescence; and, in fact, some time after, when the violence of the effervescence, and of course the production of inflammable air, begins likewise to diminish; and at last, when the effervescence is hardly perceptible, the needle is found to stand farther from the vessel containing the filings, &c. than it stood before the vitriolic acid was added, which diminution of attraction is certainly owing to the loss of phlogiston; it being well known, that iron is less and less attracted by the magnet in proportion as it approaches nearer to the calcined state.

As a single experiment ought not to be depended upon, when an error may be occasioned by many concurring circumstances, I repeated this experiment with great precaution, taking care that nothing might shake the needle, or the rest of the apparatus; but the result was nearly the same,

same, the attraction between the iron filings and the needle being at first increased by the action of the vitriolic acid.

In order to ascertain that this effect was not owing to the heat generated by the effervescence, the pot, with some iron filings, was placed near the magnetic needle, as before; then some boiling water was poured upon the filings, which heated them much more than the diluted vitriolic acid could have done; but the magnetic needle was not moved in the least from its original situation.

The suspicion which occurred next was, whether the effervescence might not agitate the iron filings, so as to bring a greater number of them to that side of the vessel which stands contiguous to the magnetic needle. In order to obviate this objection, the experiment was repeated with a single piece of steel wire, twisted in various directions, so as to be admitted into the pot; in which case the metal presented a large surface to the acid, and it was not subject to be moved by the effervescence.

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The result was similar to that observed with the filings, *viz.* the attraction was increased by the action of the acid on the wire: and here follows the particular account of the experiment.

About six yards of clean steel wire, somewhat less than one-fiftieth of an inch in diameter, being twisted in various directions, was put into an earthen vessel, which was placed near the south end of the magnetic needle, which in consequence of that was drawn from its natural situation, *viz.* from 281° to 280° . After adding the diluted vitriolic acid, a strong effervescence commenced, and the needle came to $279^{\circ} 47'$. About five minutes after, it stood at $279^{\circ} 35'$; five minutes after this, it stood at $279^{\circ} 30'$. And a little after this observation, it appeared to be even somewhat nearer to the pot than the abovementioned point. The experiment was then discontinued; and on removing the pot, the needle went back to its original situation, *viz.* 281° , which shewed, that its alteration, during the process,

cess, was occasioned by the action of the acid on the steel, and not by any extraneous cause.

On examination, the wire was found only blackened on its surface, but not nearly consumed; I had, therefore, the curiosity of trying the same wire again, and accordingly it was placed, in the same vessel, near the magnetic needle, which attracted the latter from its original situation 281° to 280° . After having added the acid, the needle came nearer, as in the preceding experiment; and a short time after it stood at $279^{\circ} 30'$, at which time the pot was removed, there being no occasion to continue the experiment any longer.

On pouring the liquor out of the pot, the wire did not appear to be much wasted. The pot was then replaced near the needle, so as to attract it a little, as before; but on pouring boiling water upon the wire, a pretty brisk effervescence took place, and the needle was, in consequence, attracted still nearer. This experiment shewed, that though the diluted acid had been

been poured out, yet there remained a quantity of it adhering to the wire, which was sufficient to renew the effervescence, when assisted by the heat of boiling water.

Upon the whole, it appears, that the action of vitriolic acid upon iron or steel increases their attraction towards the magnet; that this increase of action has a limit, after which it begins to decrease; and that this limit seems to come sooner when iron than when steel is used; but, however, with regard to this last particular I am not yet quite certain, since, in the experiments hitherto made, the variety in the shape or bulk of the iron or steel may have occasioned a considerable difference.

After the result of those experiments, it was natural to examine the effect which other acids might have on iron and steel; therefore the above-mentioned experiment of the steel wire was repeated with nitrous instead of vitriolic acid; the result of which was, that the attraction between the magnetic needle and the wire was increased, but not so much as when vitriolic acid had been used. The maximum
of

of the attraction seemed to come sooner when nitrous than when vitriolic acid is used ; after which limit the attraction decreases much faster in the former than in the latter case, which is evidently owing to the metal being more easily dephlogisticated and dissolved by the nitrous than by the vitriolic acid.

The marine acid was tried next ; but, notwithstanding all the precautions I could take, it always occasioned a very weak effervescence, and the needle was not in the least affected by it.—A strong effervescence seems necessary to increase the attraction between the magnet and iron or steel.

CHAPTER V.

Promiscuous experiments, and some thoughts concerning the cause of the variation of the needle.

THE following experiment will show, that an exceedingly small quantity of iron will render a body sensibly capable of being attracted by the magnet. Having chosen a piece of Turkey-stone, which weighed about an ounce, I examined it by a very sensibly magnetic needle, and it did not shew the least degree of attraction, the needle not being moved from its usual direction by the vicinity of any part of the surface of the stone; I then weighed a piece of steel, with a pair of scales that turned with the twentieth part of a grain, and afterwards drew one end of it over the surface of the stone in various directions. This done, the piece of steel was weighed again, and was

found to have lost so small a part of its weight as not to be discernible by that pair of scales; yet the Turkey-stone, which had acquired only that small quantity of steel, affected the magnetic needle very sensibly.

Chemistry seems not to afford any means by which so small a quantity of iron may be decisively detected in a body that weighs one ounce. Hence it follows, that though no iron can be discovered in a body by chemical methods, yet it should not be concluded, that the said body, if it affect the magnetic needle, does not owe its magnetism to some small quantity of iron concealed in its substance.

Having examined the magnetism which iron acquires from the earth by mere position, in bars of various lengths, I always found them possessed of only two poles, even when the bars were about twenty feet in length; one half being possessed of one polarity, and the other half of the contrary polarity. Sometimes, indeed, I found more than two poles, but then the bar was not of a uniform nature, and its poles

were not easily reversed by inverting the position of the bar.

After having thus related the result of experiments, I may be permitted to add a few thoughts concerning the application of those observations towards accounting for the variation of the magnetic needle.

This wonderful phenomenon has, since it was first discovered, employed the thoughts of very able philosophers ; many hypotheses having been offered, not only for its explanation, but even to foretel the future variations in various parts of the world. I need not detain my reader with a particular history of those hypotheses ; but shall only observe, in general, that neither have their predictions answered, nor were any of them founded upon evident principles. The supposition of a large magnet being inclosed within the body of the earth, and of its relatively moving with respect to the outward shell or crust ; the supposition of there being four moveable magnetic poles within the earth ; the hypothesis of a magnetic power, partly within and partly without the sur-

face of the earth; together with several other hypotheses on the same subject, are not only unwarranted by actual experiments, but do neither seem analogous to the other operations of nature. The late ingenious Mr. Canton, F. R. S. was the first, who endeavoured to account for the daily variation of the magnetic needle by the heating and cooling of the magnetic bodies in different parts of the earth's surface; which was in consequence of his having first observed, that the action of the magnet on the needle was diminished by heating, and increased by cooling*.

Following Mr. Canton's judicious method of deriving the explanation of natural appearances from properties actually proved by experiments, I think, that the increase and diminution of magnetic attraction, by heating and cooling of the magnet, as observed by Mr. Canton, together with the result of the experiments described in the preceding Chapter, seem fully sufficient to account for the general variation of the needle.

* Phil. Trans. Vol. LI. p. 398.

If we collect under one point of view all the causes hitherto ascertained, which can increase or diminish the attraction between magnetic bodies, we shall find, that the attraction between the magnet and iron, or between magnet and magnet, is increased by cooling, by a regeneration of iron, or phlogistication of its calx, and, within certain limitations, by the action of acids upon the iron; that this attraction is diminished by heating, and by the decomposition of iron; and, lastly, that it is probably annihilated by a very great degree of heat.

These truths being premised, it must be considered, first, that, according to innumerable observations and daily experience, the body of the earth contains almost every where ferruginous bodies in various states and bulks. Secondly, that the magnetic needle must be attracted by all those bodies, and its situation or direction must be determined by all those attractions considered together, *viz.* from their common centre of action. Thirdly, that by removing or altering the degrees of

of attraction of some of those bodies, which are situate on one side of the magnetic meridian, more than of those situated on the other side, the above-mentioned common centre of attractions, and, of course, the direction of the magnetic needle, must be altered, which, in fact, is the variation of the needle. And, lastly, that this alteration in the attractions of some of the ferruginous bodies in the earth must undoubtedly take place, it being occasioned by the parts of the earth being irregularly heated and cooled, by the action of volcanos, which decompose or otherwise alter large masses of ferruginous substance; by earthquakes, which remove ferruginous bodies from their original places; and we may add also by the *aurora borealis*; for though we are as yet ignorant of the cause of that surprising phenomenon, it is, however, certain, that the magnetic needle has been frequently disturbed when the *aurora borealis* appeared very strong.

The magnetic needle, therefore, being necessarily affected by these causes, and they appearing sufficient to account for its varia-

tion, it seems unnecessary to have recourse to other hypothetical causes, which are not established on actual experience.

In order to exemplify this explanation of the variation in a familiar manner, I made the following experiment:—Four earthen vessels were disposed round the magnetic needle, two near its south, and the other two near its north pole, but not at equal distances. In one of those vessels there was placed a natural magnet; the second contained several small bits of magnetic steel mixed with earth; and in each of the other two there were put about four ounces of iron filings. Things being thus disposed, and left undisturbed for about half an hour, the needle remained unaltered. Then the pieces of magnetic steel and earth were stirred with a stick, in consequence of which the needle was agitated. After this, some diluted vitriolic acid was poured upon the filings in one of the vessels, the action of which attracted the needle that way; but whilst the needle remained in that situation, some diluted vitriolic acid was poured upon the

iron

iron filings in the other vessel, which stood on the other side; in consequence of which the needle went back again towards its former direction. Whilst the effervescences were going on in the two vessels, the magnet in the first vessel was heated by means of boiling water, which occasioned another alteration in the direction of the magnetic needle; and thus, by altering the state of the ferruginous substances in the vessels, the needle's direction was altered, in evident imitation of the natural variation.



A P P E N D I X.

A D D I T I O N S.

To page 10.—In the process for converting cast iron into malleable iron, besides the action of heat and air, the metal is also hammered in various directions by heavy hammers.

To page 131.—Amongst the other points of analogy between magnetism and electricity, the following observation must be enumerated; *viz.* that when the *aurora borealis* (which has been thought to be an electrical phenomenon) forms a luminous arch towards the northern part of the horizon, the most elevated part or middle

middle of that arch is generally in the magnetic meridian.

To page 153.—In the usual construction of magnetic needles, the points or extremities of the needle, which indicate the divisions on the graduated circle, &c. are below the point of the needle's suspension; hence, when the needle vibrates not horizontally but like a pendulum, those points cannot be steadily directed to the same divisions; to avoid which, in the best sort of needles, especially those used for variation compasses, two pieces of other metal are affixed to the extremities of the needle; which pieces are first bent a little way upwards, and then they are turned again horizontally, so as to terminate in the same line with the needle's point of suspension.

To page 162.—The pivots of the jimbols of this, as well as of the common sort of compasses, must lie in the same plane with the point of suspension of the needle or card; in order to avoid, as much as possible, the irregularity of the vibrations.

A LETTER to the AUTHOR.

Dear Sir,

When you was pleased to mention your having inserted, in your new publication on Magnetism, the general cases I had furnished you with, respecting the declinations of the magnetic needle which would result from every possible assumed position of the magnetic poles, supposing the earth to be one great homogeneous natural magnet; I wished that you had added, as an example of the last and most important case, the real state of the magnetical declinations about the middle of this century; which, from the best observations I could then procure, I had also committed to paper above twenty years ago. But I find it would now come too late for your Printer; and, upon farther consideration, I am of opinion, that it would be of much more consequence, if either yourself, or some of the other ingenious Members of the Royal Society, would take the trouble of comparing the magnetical observations made during the different voyages which, by order of his present Majesty, were all undertaken

undertaken and performed during the time I was abroad; and from the whole, together with such other helps as they might have access to, if one general chart, such as Dr. Halley's, was now published, it would not only prove a valuable present to our modern navigators, but might also furnish a material step towards the investigation of this curious and interesting subject.

It is very remarkable, that when Captain Cook, in his second voyage, crossed the line of no declination, which passes through the continent of New Holland, the declination of his compasses altered about 14° in two days run: again, in his last voyage, though not so far south, the alteration of the declination, in proportion to the distance, was greater than usual near to that line. The dipping-needle likewise shows a considerable degree of inclination upon this line. In short, from various considerations it would appear, that if this Earth has the common properties of a natural magnet with only two poles, one of them must be situated in this line; and, though not within the 60°

of latitude, as Mr. Euler imagined, yet it may possibly be found not far from the 70° . If, therefore, it appears practicable to sail to the 70° of south latitude, or beyond it, about the meridian of Botany Bay, keeping in east declination; and then to run westward till the west declination becomes evident: if at the same time they have a dipping-needle on board, that without much trouble could give the magnetic inclination at sea with a tolerable degree of accuracy*; and about a hundred weight of soft iron, with a good balance, I cannot help thinking that some curious discovery might be made.

The ingenious M. Maupertuis, in his letter to the late King of Prussia on the advancement of the sciences, among other curious articles, having mentioned a northern voyage, adds, “to observe the phenomena of the loadstone, on the very spot from whence it is supposed to

* See the description of my dipping-needle, page 168, and in the Philosophical Transactions Vol. LXV.

“ draw

"draw its original influence." But such voyages were not in the power of Frederic the Great. It is to our present gracious Sovereign that the world will ever be indebted for such noble, extensive, and disinterested discoveries. All access to the north pole having been proved impracticable, by the voyages of Lord Mulgrave and Capt. Cook, it now only remains to be determined, whether it is possible to come at the south magnetic pole; which, for the reasons already mentioned, seems at least more probable, if it be judiciously attempted.—Along with this, I have sent you a few cursory observations on the declination, which I have always considered as the most important, as well as the most curious part of the subject of magnetism. If you chuse to publish them in your Appendix, you are not to consider them as complete or infallible: I only wish to take this opportunity of exciting enquiry into this very interesting subject; and when your Book comes to a second edition, I hope to have it in my power to communicate

communicate something more satisfactory on this head; for I ever am,

Dear Sir,

Your most obedient

humble servant,

J. LORIMER.

Mr. CAVALLO.

1st. That line, which I shall call the Atlantic line of no declination, seems to take its origin from the north magnetic pole, and crossing the different meridians in a south-easterly direction, resembling in form the long letter S, it traverses the continent of North America, enters the Atlantic ocean to the northward of Charles-Town, and so proceeds towards the south pole. Upon the west side of this line there is east declination, and upon the east side thereof, west declination; which last gradually increases as you go to the eastward, till you get beyond the Cape of Good Hope, or about mid-way between the Atlantic and the East-India line of no declination, where it amounts to 31° , about the latitude of 48° south;

Z

and

and then it regularly decreases to the East-
India line of no declination.

Again, as you go to the eastward of that line of no declination, the east declination increases rapidly till you get to the eastward of New Zealand, where it is upwards of 13° even in that latitude; but from thence as you proceed eastward, for about 40° in longitude, this declination appears to decrease; and again it increases till you are to the eastward of Cape Horn; where, in the latitude of 51° south, it amounts to $21^{\circ} 28'$, and then gradually decreases to the Atlantic line of no declination aforesaid. Upon the whole, it would appear, that these observations agree pretty nearly with the 4th general case which I formerly sent you, except in that decreasing east declination to the eastward of New Zealand. But admitting that the vast body of water in the great Pacific ocean, which cannot have any magnetic properties, should have no effect in producing this irregularity, yet we are not to expect even that the solid parts of this globe can be so uniformly

formly magnetical throughout, as to answer entirely with calculation in every part thereof.

2d. The magnetic needle not only declines, or varies from the true north, differently in different parts of the earth at any one time; but likewise in the same place this declination is different at different times: I would therefore call it, by way of distinction, the variation of the magnetic needle.

3d. At London and Paris, where the most accurate observations have been made, towards the latter end of the sixteenth century (and we cannot pretend to much earlier observations) there was between 11° and 12° of east declination, which gradually decreased; so that in less than a hundred years afterwards, there was no declination at all in those places. From 1657 at London, and 1666 at Paris, a west declination began, and has ever since increased, gradually though not uniformly, or in the direct proportion of the times; for such is the nature of the magnetic de-

clination, that, like the apparent motion of the planets, sometimes it is faster, sometimes slower, and at other times it is stationary; analogous also to the elongations of the inferior planets, at one time it is to the east, and at another time to the west, alternately.

We may further observe, that the declination lines of the same name, have always respectively passed London some years before the same lines arrived at Paris; and the like observations have been made in other parts of the northern hemisphere: that is, in this hemisphere, the Halleyan lines have regularly passed those places first which lay most westerly; and so in order those which lay more to the eastward. For in the latter end of the sixteenth, and the beginning of the seventeenth century, there was an eastern declination over most parts of Europe, while on the coast of North America a west declination prevailed; the line of no declination being then situated about the Azores. This line of no declination has ever since moved gradually

dually eastward, the lines of east declination receding before it, while those of the west declination have regularly followed it.

4thly. In the southern hemisphere, however, it is quite otherwise; for about the latter end of the sixteenth century, a line of no declination passed near to the Cape of Good Hope, upon the east side of which there was west declination, and upon the west side thereof east declination; each of which declinations, in going eastward or westward, gradually increased to a certain degree, and then in the same manner decreased to nothing, somewhere to the eastward of Java, one of the East India islands.

The declination in the Pacific ocean has not as yet (in 1775) been so fully ascertained, only in general we find, that the declination is easterly over most part of that extensive ocean. The line of no declination, which was then situated a little to the eastward of the Cape of Good Hope, has ever since been moving to the westward, and the lines of east declination have gradually re-

ceded before it, while those of the west declination have followed it with a proportional pace; so that at the Cape of Good Hope there is now a considerable west declination (about 22°), and the line of no declination has moyed many degrees to the westward thereof.

5th. From the preceding observations then it plainly appears, that the Halleyan lines in the southern hemisphere do gradually move from east to west, while the motion of those lines in the northern hemisphere is from west to east; and here we shall rest the matter for the present.

I just beg leave to observe, that in treating of this subject, I have all along only endeavoured to explain the manner in which magnetism acts upon this globe; yet if the preceding conclusion is admitted, *viz.* that the progressive motion of the lines of declination in the northern hemisphere is constantly from west to east, and in the southern hemisphere from east to west, this discovery will be of as great use to us in framing, regulating, or judging of our

future charts or tables of the declination, or variation of the mariners compass, and will answer the purposes of navigation as well, as if we were thoroughly acquainted with the primary causes of all the phenomena of magnetism.



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